REGIONAL FORESTRY SECTOR MODELLING OF OPTIONS FOR INDUSTRIAL FOREST PLANTATIONS IN INDONESIA

A Thesis
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the degree of
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by
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to my wife ***Donna***
and
to my children ***Danielle, Hannah & Jonathan***

For surely I know the plans I have for you, says the LORD,
plans for your welfare and not for harm, to give you a future with hope.

Then when you call upon me and come and pray to me,
I will hear you.

When you search for me, you will find me; if you seek me with all your heart.
[Jeremiah 29:11-13]

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Abbreviations

ADB	Asian Development Bank
asl	above sea level
Cashdata	Cash flow sub totals (RMS-2020)
Cashrep	Cash flow report (RMS-2020)
Costdata	Detail of costs (RMS-2020)
Crop type	is an aggregate of stands which may differ as to age but which are otherwise described in common, at least on the average (Allison, 1989; p.35).
Detdata	Detailed data (RMS-2020)
DM (s)	decision maker (s)
DSS	Decision Support Systems
e.g.	for example
Fig	Figure
FOLPI®	Forestry-Oriented Linear Programming Interpreter
Genrep	General report (RMS-2020)
GIS	Geographic Information Systems
GoI	Government of Indonesia
GP	Goal Programming
ha	hectare
HGW®	Havard Graphics *Windows*® version 1.0 - a proprietary drawing tool
HTI	*Hutan Tanaman Industri* (Industrial Forest Plantation)
HTIT	*Hutan Tanaman Industri*-Transmigration (Industrial Forest Plantation-Transmigration)
IGT	Industrial Grade Timber
IRR	Internal Rate of Return
ITTO	International Tropical Timber Organization
LP	Linear Programming
m^3	metre cubic
Mapinfo®	Mapping Information Systems Corporation (1992) - a proprietary GIS tool
MES	minimum economic size
MINMAX	minimise the maximum goal deviation
MINSUM	minimise a sum of weighted goal deviations
MODM	multi-objective decision making

MoF	Ministry of Forestry
NGO	Non Governmental Organisation (or LSM:*Lembaga Swadaya Masyarakat)*
NMFP	National Masterplan for Forest Plantations
NPV	Net Present Value
NZFP®	New Zealand Forest Products Limited
NZFRI®	New Zealand Forest Research Institute Limited
Pers. comm.	Personal Communication
PP	Pulp Plantation
RHS	right hand side
RKL	*Rencana Karya Lima Tahunan* - Five-Year Working Plan
RKT	*Rencana Karya Tahunan* - Yearly Working Plan
RMS-2020®	Resource Maturity Simulator - 2020
Rp.	*Rupiah* (Indonesian currency)
Sumdata	Summary data (RMS-2020)
Sumrep	Summary report (RMS-2020)
TC/ha	total cost per hectare ($/ha)
TGHK	*Tata Guna Hutan Kesepakatan* (Consensus Land Use Plan)
U/L	upper and/or lower limits
UNEP	United Nations Environment Programme
util	utility measurement
Wecrep	Warnings, errors and comments (RMS-2020)
WPPC	Watershed-Protection Part Commercial
XA®	Extended Application - a proprietary LP package
Yldrep	Yield report (RMS-2020)

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I wish to thank the Ministry of Forestry of the Republic of Indonesia for 3½-year scholarship. Although it did not sustain me over the last six months, is still due to them. This study is dedicated to the Indonesian forestry where many constructive development options are possible and available. *"It is only natural, therefore. that we should never see the picture whole. But the universal goal - the attainment of harmony - is apparent. The very act of perceiving this goal and striving constantly toward it does much in itself to bring us closer and, therefore, becomes an end in itself"* [1].

I am grateful to my beloved wife, Donna, and my daughters Danielle and Hannah, and my son Jonathan for sharing our good and hard times and their patience, endurance and cares. I have appreciated the love and support of my parents, brothers and sisters.

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[1] from Admiral Richard E. Byrd's (1938) account of his struggle to reach the South Pole, *Alone*. Putnam, NY.

Abstract

Regional resource planning and decision-making for industrial forest plantation development increasingly involves participation by members of the public. Motivation to maximise or minimise the degree to which groups with various interests can satisfy their individual objectives should recognise outcomes arrived at in a consensus decision-making environment. In this study, a planning framework is devised and adopted, which describes a regional planning system prepared in order to assist in the design and evaluation of strategic industrial forest plantation development in Indonesia.

The central component of this planning system is interactive Multi-Objective Decision Making (MODM) modelling with linkages between optimisation and simulation models. The framework of the whole planning system demonstrates the capability and feasibility of resolving important and conflicting objectives through discussion and communicative decision processes that can be reinforced with modelling sensitivity outputs. In other words, a methodology is developed that allows strategic options for plantation planning to be analysed interactively. The MODM models here are MINMAX and MINSUM goal programming formulations. This model has various features that characterise industrial forest plantation development planning, including physical production, social, economic, environmental, and location aspects. This formulation, moreover, has several advantages such as capturing the essence of the multi-objective decision making problem, encompassing the entire range of feasible tradeoffs among all objectives through parametric programming in order to derive forestland allocations optimally, as well as serving important implementable and practical interests.

A minimum economic size (MES) spreadsheet-based model is run to determine profitable plantation sizes by using financial criteria such as IRR and NPV. The MES model outputs are then incorporated within MODM models.

A major part of the research reported here was to develop a way of transferring data between simulation and LP models directly through file transfers, and transferring LP-derived solutions directly back to the simulation model. This linkage has several advantages: for example, theoretically optimal LP solutions are usually unrealistic in practical or implementational terms because of administrative, social, environmental and other similar problems facing forest management; whereas simulation allows one to explore the effects of deviations from "optimal" LP solutions, and to simulate both in more detail and in broader aggregations of things such as age classes, log types and locations. If measures, e.g. wood and financial flows, are unsatisfactory, some constraints are modified and formed for the relevant LP model utilising, for example, the future log assortment flow consequences and the tradeoffs among them. The automated linkage between optimisation and simulation models provides easy data and solution transfers so that decision makers and stakeholders may gain detailed insights before any consensus decisions need to be made.

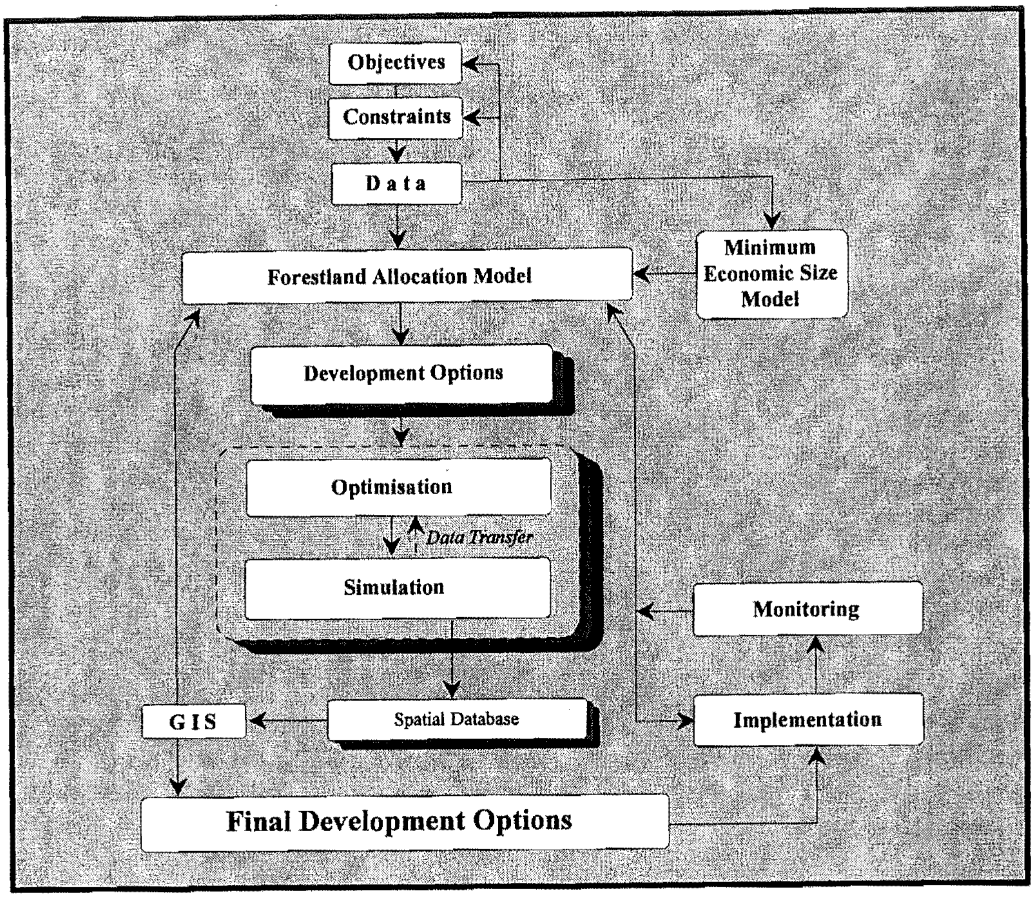

Figure 1.A. Integrated Regional Planning Diagram

A geographic information system (GIS) is utilised to enhance pictorially the preferred solutions, information, and appearance.

The whole planning system is demonstrated and tested in an indicative case study. The results display the major advantages of consistency, clarity and simplicity of the approach to regional forestland allocation.

The framework and results at this stage are only preliminary, because some data are still incomplete and unrefined. This study is, therefore, an initial description and explanation of methodology and an indication of the nature of desirable results rather than a firm policy recommendation pertaining to the case study area. In principle, the framework could also become multi-temporal by creating each variable in a time-dependent fashion.

The planning system developed has the ability to incorporate social, financial, environmental, and technical variables in a comprehensive participatory development process. The ultimate value of the quantitative information represented in this framework (or methodology) through a background case study analysis is its ability to facilitate policy formulation to satisfy decision-makers and stakeholders when making informed choices in fundamental management decisions.

Chapter 1. Introduction

A world without forests is unthinkable (FAO, 1993;p.9)

1.1. Background

A major problem which DMs (decision makers) and stakeholders face when allocating resources, is where and how to allocate the resource to its best overall effect. Resource management problems involve developing an allocation plan, which is consistent with perceived demands, the physical, spatial, local or regional characteristics of the resource, and the decision-making process. The options required in developing such a plan comprise what, where and how resource options should be financially and technically selected, spatially allocated, socially accepted, and how these options can be presented in the decision-making process in an interactive manner.

Decisions regarding resources affect not only the downstream processing plants, but also have significant impacts on the economic realisation from the forest resource, the choice of resource combinations, and the impacts of non production outputs such as environmental protection or conserving biodiversity. Increased attention needs to be given to non technical aspects such as local priorities and the involvement of private or local stakeholders both in the decision-making process and the subsequent development. At the same time it is essential that regional sector modelling of options for resource development be firmly established in the realities of the present with its overwhelming dependence on the availability of resource-based (forestland) areas, funds, and technical levels of competence.

Industrial forest plantations now involve intensive management on a spatially large-scale basis and long-term period in order to satisfy various demands and markets. Considerations in allocating yields have to include factors beyond simply wood supply capabilities. For example, *how large and how distributed should plantations be for commercial production purposes, while at the same time satisfying other functions and purposes. What should the species combinations be? Who should be responsible for the resource development? How should the resources be optimally allocated?*

These considerations become even more complex when decision-making processes involve conflicting and compromising features that are central and critical aspects of the problem (Weintraub and Navon, 1986). Moreover, derived options should capture the concern of politicians, the public, and the resource professionals who could materially affect resource use patterns (Hewett et al., 1982) and also the location, species choice, crop type regime, technological inputs and management regime (Sedjo, 1986). Whyte (1995) suggests appropriate designs for forestry planning models need to cope more effectively with political considerations and participatory decision-making. Overall, the economic, political, and social effects of any resource development on an extensive scale would be substantial (Kanowski et al, 1992).

Most applications of industrial forest plantation planning models in the published literature are not solved in an integrated and interactive manner. They are more in problem-solving for local or individual locations, and for single specific objectives, or do not address the full range of decision-making process required for planning at the regional level.

The development of good industrial forest plantation management strategies offers many challenges, some of which cannot be met only by further extensions to the traditional approach (Kanowski et al., 1992). In addition, the traditional approach is appropriate in industrial world societies but not always in much of the non-industrial world where rural communities and land scarcity are more typical (Sargent, 1990).

Public or stakeholders should be involved more actively in the decision-making process. This is the reason for recognising that industrial forest plantation development planning should continue to evolve toward sustainable development. Furthermore, public or stakeholders' involvement, which is crucial, should be allowed to achieve importance in the evaluation of industrial forest plantation decisions or options (Sharma et al., 1992).

This study is an attempt to address these requirements and complexity of planning systems in regional sector modelling of options for industrial forest plantations. It focuses on the integration of decision support models for such applications in an interactive and transparent manner for decision-making. The second part of this chapter describes the context within which decisions or options are derived and highlights the need for greater integration of other planning aspects. The objectives of this study are then presented in section 1.3, and the last section defines the scope of this study.

1.2. Statement of The Problem

Forest management of the state forests in Indonesia is mandated by Act No. 5 (Anonymous, 1967), directing the State by the Ministry of Forestry to consider all resource outputs in its management decisions, i.e. to control, regulate, manage and administer those State forestlands and forest resources.

The best management strategy for any location of industrial forest plantation depends on the management objectives, the resource availability, the inherent or imposed constraints, and the decision-making circumstances (Kanowski et al., 1992).

Many factors including political, social, and technical constraints, lack of location specific production and non production data, and shortage of decision support methodology could restrict the realisation of industrial forest plantation development plans (MoF, 1989; Kanowski et al., 1992; Sharma et al., 1992; Anonymous (APHI), 1993; MoF, 1995).

Managers must familiarise and involve the public in their planning. Furthermore, they must carefully evaluate as many options or consequences as possible, for example, the production, social, and environmental consequences of their management strategies (or lack of them). These requirements need to be addressed explicitly.

DMs (including policy makers, forest planners, and experts or analysists) and stakeholders will certainly need to consider and be aware of these and other factors that ultimately limit the quality and quantity of regional industrial forest plantation management.

Improved information for decision-making in forest management can possibly be achieved by taking advantage of modern methodologies; namely - system analysis, ecological modelling, and information systems (ITTO, 1993).

There are several advantages of this sequential system when compared to single-model approaches to model development:

(i) this system guarantees coordination of the overall decision making process, while enabling different aspects to be modelled separately in order to be transparent in terms of a common knowledge base value sets, and;
(ii) further related to point (i), this allows characteristics of particular decision aspects (e.g. minimum size, allocation, financial and wood flows) to be built into corresponding models with little complication. These advantages are illustrated with the models for different aspects in the planning problem presented here.

The decision framework in particular for forestland allocation (Figure 3.1; p.29) has the advantage of reducing the complexity of the decision making process into an interactive one. For example, in a practical way proposed stakeholders' plans may not need to be modified individually, as they may be too costly or need more time. This framework allows a further deliberation of options, formulation refinement and forum for consultation and discussion for global consensus among decision makers and stakeholders.

Three major points that might influence the decision-making process are as follows.

1. A point which might influence the decision-making process is that it is a result of decision-making and implementation without complete information. This indicates that the more information available, the greater are the opportunities for determining satisfactory solutions. Furthermore, there may also be a lack of clearcut institutional objectives (ADB, 1987).

2. The information flow to the affected individuals or groups is influentially important. The more individuals or groups that are included or the greater the degree of decentralisation in the decision-making process, the more feasible it is that desired deliberated solutions will be obtained.

3. The influence location of forestland development is evaluated within wider land-use systems. The more changes anticipated in forestland-use, the more information is needed for trade-off evaluation.

According to the work of the National Masterplan for Forest Plantations or NMFP (1993) at the national level in Indonesia and preliminary work at the provincial or regional level, there would be 6.67 million ha of industrial forest plantations which would be required to be in production by the year 2030, in order to satisfy Indonesia's long-term wood demand. This includes 2.13 million ha for the East Kalimantan region. Forest planning requires procurement of knowledge of financial, social, environmental and technical performance of trees. In addition, such things like productivity, wood prices for various log types, *etc* with respect to various options for management regimes and species are needed.

This proposed industrial forest plantation is important factor ensuring its future contribution in future wood supply for supplementing the decreased wood supply from natural forests (NMFP, 1993). Attention has recently shifted from a view of forests as fiber factories to multiple-use forestry (Kanowski et al., 1992). Thus, this procurement is required explicitly.

This study, therefore, was initiated with the rationale that:

(i) there is a need for modelling methodologies which DMs and stakeholders can use to assist in making decisions in an integrated and interactive manner, and;
(ii) the requirements for sustainable management for industrial forest plantation include not only the involvement of local community or stakeholders but also the availability of appropriate methods and adequate finance.

There are several requirements for such a planning methodology. The first is that resulting plans must be financially acceptable for the various crop type options. The second requirement is that the deliberated development plans must be feasible and as near optimal as possible.

Investments in industrial forest plantations require planning systems that are capable of meeting stakeholder needs and capturing various interest group needs by means of:

(i) a robust system capable of being used to develop feasible strategic plans for a
(ii) allowing flexibility in changing intentions from various interest groups to provide a consensus starting point, and;
(iii) simplicity and ease of use for real-world problems.

1.3. **Objectives of The Research**

The research objectives are:

1. to identify the kinds of:

   1.1. key management assumptions and objectives in regional plantation planning problems, and;

   1.2. minimum data requirements and data collection required for appropriate modelling.

2. to develop an integrated modelling methodology for regional industrial forest plantation development that allows economic and non economic factors to be considered and addresses the need for interactive and participatory decision-making.

3. to develop specific models that

   3.1. are capable of deriving minimum economic size for industrial forest plantations on spreadsheets, and;

   3.2. are capable of allocating various management regime options under specific multi-objective decision-making.

4. to develop an integrated modelling system suitable for studying long-term forest sector development options at a regional level including the linking of LP and simulation models.

5. to indicate, by way of a background case study example from Indonesia, the best mean of determining regional management options for industrial forest plantations which appears most suitable, utilising the sector model referred to in (2) and (3) above.

6. to recommend means of data collection and analysis, and management requirements in this planning system that are needed to derive rational decisions.

1.4. **Scope of The Study**

The scope of this study relates to aspects of integrative and interactive planning systems. The focus is on resource allocation and its implications for satisfying commercial and non commercial objectives in regard to multiple objective decision-making problems. In addition, it is intended to integrate economic, environmental and social benefits and costs within a balanced management system.

The problem is considered from the point of view of resource developers who supply non pulp and pulp logs to meet various demand or serve different markets. Such developers can include private or state-owned forest companies, and domestic/local or international companies. The decision-making process involves DMs, stakeholders, and analysts or experts. DMs include policy makers. Stakeholders refer to a category of private or state-owned forestry companies, NGOs, forest dwellers, and local communities. Furthermore, this process allows opportunities for DMs and stakeholders to consider the resource allocation problem in terms of technically defined and deliberated development options via discussion and consultation. If necessary, further refinement formulation would be able to be carried out.

Resource allocation is defined by crop type which can be categorised in terms of location, species, and management regime. Crop type is defined as an aggregated of stands which may differ as to age but which are otherwise described in common, at least on the average (Allison, 1989).

1.5. Structure of The Thesis

Chapter 2 reviews the use of models and modelling in forestry, and discusses the major developments in resource allocation decision support systems that have appeared in the published literature. The discussion focuses on the features and major developments of various classes of models used in plantation development decision-making, and highlights the perceived gaps in the integration and interactive aspects of existing planning systems. Chapter 3 documents the development of a framework for forestland allocation that is proposed for integrated modelling of economic, environmental, and social values, and provides detailed features, including a spreadsheet-based minimum economic size model and the mathematical structure of the models within this framework. In Chapter 4, background for using the planning system is presented in a case study, used for demonstrating, testing, and evaluating the proposed modelling structure, as is the application of various models to the case study, together with the results of the modelling. In Chapter 5, discussion covers the results of application of the planning system. Chapter 6 summarises the major results of this study, and draws the major conclusions from the development of the modelling system as applied to the case study. In the last chapter, some suggestions for potential future work which arise from the developments in this thesis are presented.

The detailed data input to this study, the spreadsheet-based model structures, and the macro files are contained in appendices and in hardcopy or diskette form.

Chapter 2. Literature Review

Management can never be an exact science,
but the days of 'intuitive' managers are numbered
(Peter F. Drucker)

2.1. Planning Systems: General Considerations

As pressures grow to provide increased levels of wood production and cater simultaneously for environmental concerns, almost every country's current forest resources are now at a transitional stage, in that ample quantities of available wood have diminished (MoF, 1989). In order for the Indonesian forest sector, for example, to continue to play a sustainable role in the country's economic development, long-term policy analysis in the forest sector is needed, especially at the regional level. The combination between different regional level forms the basic for sustainable management for the national level.

Three major components of the forest sector model to be examined here are the resources (wood supply), forest industries (wood processing), and markets (wood product demand and supply). All these components should be analysed jointly or at least without any complete segregation from one from another because any forest sector is sufficiently complicated that interactions cannot be ignored (Kallio et al., 1987). Whyte (1990) indicates that a major problem in forest sector modelling is acquiring the skill necessary to find the right balances between the wood processing, forest products, marketing, and wood supply components.

Linking elements within the forest sector (comprising both forests and forest industries) can be accomplished with systems analysis. Systems can be regarded as groups of elements embodying relationships among the elements and their environment. Systems analysis is the representation of relationships that exist among elements of the system ordered so that the whole may be analysed (Jeffers, 1973).

Systems analysis should be directed towards the development of models and the process of modelling, through describing the system and analysing the consequences of various actions on it. Models which can be used to study systems, are representations of the real world. In other words, a model should be able to describe the structure of the system being represented so that it includes the nature of relationships among the system's elements. Extensive modelling examples of applied systems analysis have been outlined by the International Institute for Applied Systems Analysis or IIASA (e.g. Andersson et al., 1986; Kallio et al., 1987).

Important model types can be classified, according to Jeffers (1973), into word models, compartment models, stochastic models, and mathematical programming models. Word models include writing down what is known about the components of the system and their inter-relationships, and they highlight the areas where knowledge of the system is inadequate. Compartment models, on the other hand, are representations of a system as a series of compartments between which some other variables occur. They contribute to at least the initial stage of thinking about resource management systems. Stochastic models involve probability, e.g. Markov chain processes. In contrast, most mathematical programming models are deterministic. They do involve probability. They generate optimal solutions for a defined objective function which is linear in the uncertain state variables. In addition, the feasible management options are independent of the actual values of the uncertain state variables (Gong, 1994).

The essential feature of this kind of model is that it comprises a set of mathematical relationships such as equations, inequalities and dependencies, *etc* which correspond to the relationships in real world problems. Furthermore, mathematical models are able to tackle problems with a very large number of variables and their relationships, and these conditions reflect on real world managerial circumstances. This model type is the most usual tool utilised for the process of forest estate modelling (Whyte, 1990).

Given that forest sector systems are complicated entities, the problems that occur are often the result of a country's domestic and overseas development interactions. The consequences of these problems may appear at regional and various other levels. In other words, the possible alternatives to the problems are expected to be local and not global. Decomposition is needed in order to be practical for the combination of large numbers of interconnected variables (Andersson et al., 1986). Systems analysis can be decomposed at 3 or 4 levels; e.g. global, national, and regional forest (or inter-regional) analysis.

Whyte & Baird (1983) and Whyte (1990) specified vital components in forest sector modelling:

1. determining potential supplies over time;
2. forecasting market demands for various kinds of final products;
3. developing forest management and harvesting strategies along with importing products to match supply and demands;
4. transporting raw materials, intermediate and final products;
5. selecting, locating, building and operating processing plants;
6. financing the associated capital investment and foreign exchange that will be required;
7. rationalising and regulating use of energy, other raw materials and people;
8. quantifying and documenting the consequential needs for vehicles, equipment, roads, port-handling and shipping capabilities;
9. imposing realistic levels of environmental and social constraints, and;
10. providing inter-sectoral linkages.

Regarding the above list, while the points for determining supplies, developing forest management, transporting products and financing the investment are still the fundamental considerations for developing options for regional industrial forest plantation planning, imposing environmental and social constraints and providing inter-sectoral linkages need also to be implemented in the planning systems. These ten considerations become important priorities in decision-making processes.

Three significant categories of models for the forest sector are dynamic simulation, mathematical programming, and econometric spatial equilibrium models (Andersson et al., 1986; Whyte, 1990). Dynamic simulation models are able to produce scenarios for a forest sector when employing different strategies. A simulation approach is used where the solution is found recursively over time. Lönnstedt (1986) provides an example of this dynamic simulation approach for studying long-term development of the forest sector at the national level.

Mathematical programming models are, mainly linear programming (LP) or mixed integer linear programming (MILP) and goal programming models. Mathematical programming uses constraints on the initial and terminal states to restrict an optimal solution. Model solutions can be obtained by formulating a goal function. Examples of this LP approach are contributed by Whyte & Baird (1983) and Kallio et al. (1986). Johnson (1989) developed a mixed integer linear programming model for regional forest industry development. He utilised a mathematical programming modelling system to aid strategic planning and decision making for the wood-processing industry which emphasises the interface between wood supply and wood processing. While both planning systems have a similar regional focus, the modelling systems which have been developed in this study highlight an interactive decision making process in order to spatially allocate forestland for industrial forest plantation development. The planning system reported here was developed to provide an important starting point for Indonesia's long-term plantation development planning.

Spatial equilibrium models are the third significant kind of model, often required in regional analysis because of geographical variation in ecological, institutional or economic conditions. A spatial equilibrium model was employed by Adams & Haynes (1980), for example, to analyse U.S. forest products markets for long-range projection and policy analysis. Those three modelling approaches can often be utilised in combination, e.g. simulation and mathematical programming approaches for a complex regional analysis (Andersson et al., 1986).

The complexity arises mainly from the fact that many interacting issues, uncertainties and different parties are mixed up or involved in such problems. However, the focus of their given complexity can be compensated by the awareness and understanding of the whole problem and a sequential formulation of it. Furthermore, forest planning as one part of the decision making process, which includes identification of criteria, evaluation of preference and choice of decision, should be considered along with implementation and control. These parts of the decision-making process all involve consultation, negotiation, and analysis which can then be directed to ensure effective decision making (Dyson, 1990).

Forest planning problems, as well as other private and public sector planning problems, are usually very complex and cannot be fully depicted by any analytical techniques such as mathematical programming in the opinion of some researchers (e.g. Liebman, 1976; Brill, 1979). However, it is not only optimal solutions to forest planning problems that are technically useful for decision makers, but also the systematic framework surrounding and preceding these optimal solutions (Jacobsson & Jonsson, 1991). The discipline and effort required to build models can contribute more to understanding the problem and generating possible solutions, than running the models themselves. In addition, it is not looking for the models to provide an absolute answer, but to guide or assist decision-making.

2.2. **Models and Modelling in Forestry**

A model is a representation of an actual situation (Dykstra, 1984) and can be created as a logical and explicit relationship. Alternatively, it may be regarded as configurations of mathematical, physical, and biological aspects which follow specified conditions, the behaviour of which is used to understand a system (Hunter, 1987). A system itself is a collection of objects united by some form of regulatory interaction and interdependence which act together to achieve a common goal. The principal purposes of modelling are as tools to aid understanding, design, operation, prediction and control of real situations via the study of simple representations of the systems (Neelamkavil, 1987).

The need for forest planning arises from conflicts in catering for the present and the future in a balanced fashion. Forest planning itself has also evolved to meet various objectives and needs of both the private and public sectors. Planning is therefore a link between policy making and management (Whyte, 1991). Johnston (1972) summarises the nature of planning as an intellectual and technical background to policy formulation, strategies, tactics, programmes and budgets. In practice, planning is generally explained as the process of working out how to accomplish various objectives (Arnold, 1972). Furthermore, planning that generates successful consequences requires explicit, clear and attainable objectives to be accomplished.

Forest management as defined by Whyte (1988a) consists of decision-making, implementation, facilitation, and control is concerned with choosing trade-offs in order to integrate resources, people, values, information and time horizons (Whyte, 1988a). It implies carrying out interventions in complex production systems (Jonsson et al., 1993). Such production systems are characterised by a large combination of management actions that can be applied either to the whole or part of a forest over a range of time horizons. Consequently, forestry has an on-going need to develop various models for planning, scheduling, different activities, and for predicting growth and yield using the planning models to suit a variety of situations. The shortage of wood supply was the primary concern for early various forest management models, an example, was the rigid approaches to regulating wood supply through an optimal rotation model (Faustmann, 1849).

Forest management involves carrying out strategies within complex, physical, social, environmental, and biological production systems. The strategies' final products can be both wood and non-wood products and they are the result of complicated interactions between the environment, quality of the stock, management interventions, and social aspects. The purpose of forest management is to provide a basis for the allocation of resources in accordance with those strategies, so that the desired outputs can be met (Jonsson et al., 1993).

Up to now, the objectives and extent of forest management decision support systems are broad and developed in relation to their capabilities. The complexity and size of models can be regularly improved, because of increased and improved computational power. For example, for:

(i) determining optimal rotation length (such as Duerr et al., 1956; Whyte, 1988);

(ii) scheduling of harvests, management interventions, and regeneration (Johnson and Scheurman, 1977; de Kluver et al., 1980; Garcia, 1990; Villanueva, 1992);
(iii) log allocation (McGuigan, 1992; McGuigan & Scott, 1995);
(iv) forecasting of growth and yield and forest management based on growth models (Goulding, 1986; Whyte, 1989a; Temu, 1992; Valsta, 1992), and;
(v) decision support systems for forest industries (Sicad, 1993), to regional, national, international, and global trade sectoral models (Buongiorno et al., 1981; 1982; Kallio and Dykstra, 1984; Kallio et al., 1987; Johnson and Whyte, 1993).

Whyte (1989a) proposes an overall planning and management decision support system for tropical plantations in Fiji. His proposal provides a compact summary of the major issues and principles that need to be addressed in the planning and management of plantations in tropical environments.

Figure 2.1 shows the existence of linkages and inter-relationships between different elements of forest planning and management systems from Whyte (1991).

Forest growth and yield models are utilised for predicting future resource potential subject to a set of management interventions. These models can be classified into three, i.e. whole-stand/distance-dependent, single-tree/distance-dependent, and single-tree/distance-independent (Munro, 1974). Whyte (1994a) describes the kinds of information that these models need to be capable of supplying in order to produce effective plans for harvesting, utilisation, and forest management with tropical plantation experiences. Volume, height, diameter and mortality predictions are the most important components of these models which are necessary elements for planning and production forecasting tools leading to cash flow or economic models at the resource levels or plant industrial models at the processing levels. Examples of economic models include the work of Flick (1976) by using input-output technique, and Chang and Buongiorno (1981) by combining goal programming and input-output techniques.

Both growth and yield models and cash flow/economic models are able to be combined in tandem with forest estate models. The latter type is concerned with whole forests. These models are needed to evaluate long-term strategic management decisions which maximise wood flow or net present value (NPV), as constrained by predominant and predicted market scenarios. Allison (1986) and Garcia (1986) provide overviews of forest estate modelling in New Zealand and also explain the major model types and their features. Forest estate models are discussed in greater detail in section 3.3.3.

Plant industrial models can be divided into single and integrated plant models, according the classification of Whyte (1991). These models are used to aid decision making for specific production processes, such as in sawmilling, plymilling, and rough milling (Maness, 1989; Sicad, 1993; Suter and Calloway, 1994). Holmes (1976) reviews applications in forest products industries.

Integrated industrial models are used to aid decision making related to log procurement by choosing the mix of log from a variety of sources to meet the plant's requirements. Barros and Weintraub (1982) and McGuigan (1992) are examples of this kind of model.

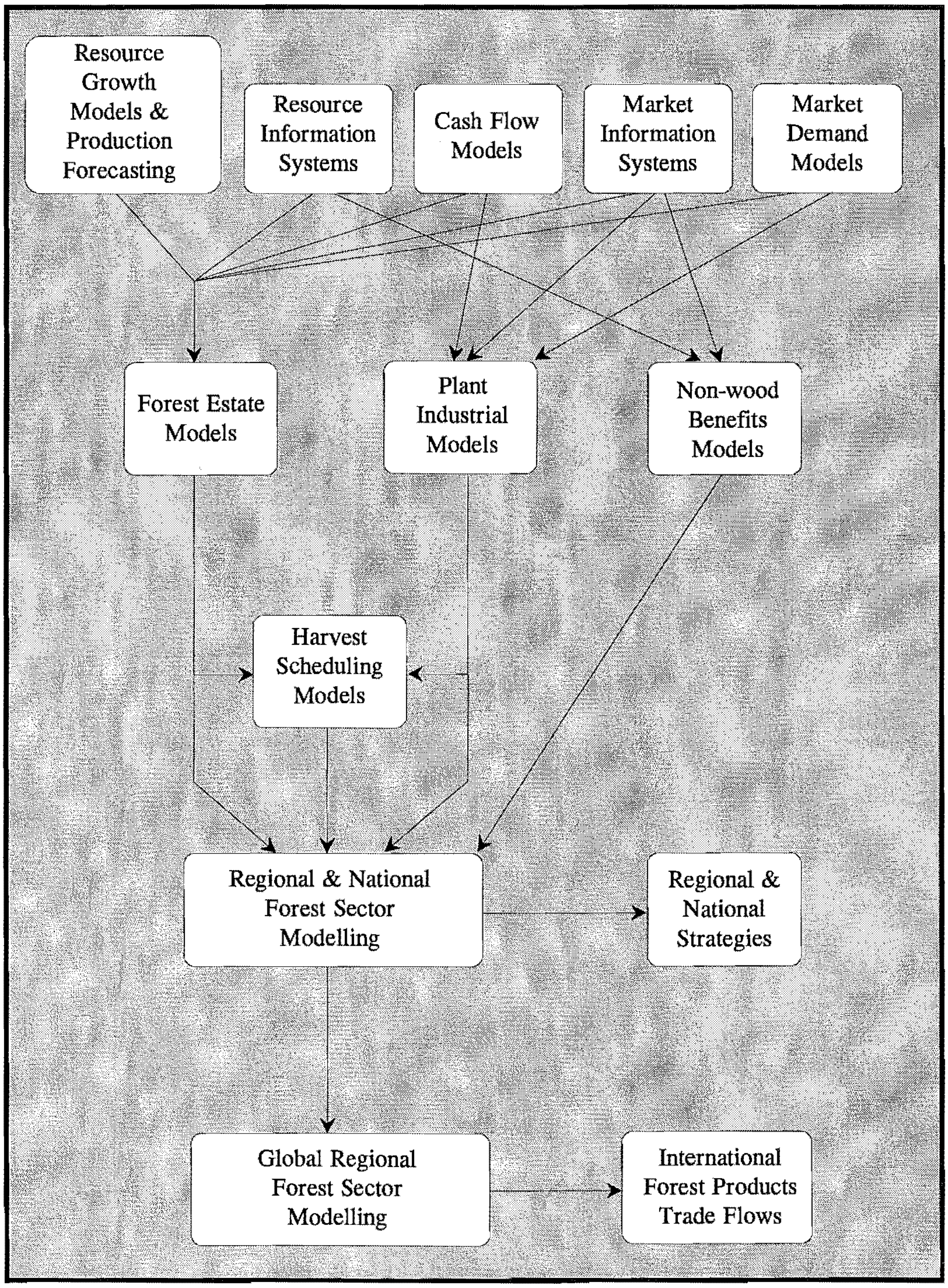

Figure 2.1. Elements and Linkages in Forest Planning and Management Systems
Cited from Whyte (1990)

Regional, national, and global sector models are concerned with long-term strategic development of production, demand, and trade of certain forest products and related externality factors at the regional, national, and global levels. Johnson (1989), Johnson and Whyte (1993) and Broad (1985) produced regional and national models; Baird and Whyte (1983) and Kallio et al., 1986 produced models at the national level, and Dyskstra and Kallio (1986) produced a global model. Simulation, mathematical programming, optimal control theory, and econometric spatial equilibrium models are the core techniques in these type of models.

The management models are dominated by independent and functional analysis for specific or combined production, utilisation and trading purposes. Whyte (1991) discusses sectoral models in greater detail, and describes the feature requirements of such models.

Forest production, utilisation and trading patterns are in one part of a rapid transition into a mix of commercial and non commercial benefits (or mix of forest products (Hrubes, 1983)) for wider users given the spatial consideration. Forest management models should be tailored to the more demanding requirements of ecosystems, and increasingly, pro-active stakeholders and public interests that are demanding a more participatory role in how decisions are made. For example, Hrubes (1983) analyses environmentally related restrictions on the timber harvesting capability at the national level. He concludes that the preferred products mixture which resulted from a combination of such factors incorporates:

(i) the managers' initiatives;
(ii) the public interest pressures, and;
(iii) policy directives.

Peterson and Peterson (1989) present an American historical illustration of public-agency conflicts and interaction within the multi-resource management decisions of ponderosa pine forests in Arizona. They explain conflicts which are presented from a public viewpoint as an effective methodology to achieve resolution and contribute to a possible agreement in the forest management. Whyte (1995) recently suggested an interactive modelling methodology that includes key utilitarian values. His interactive form tolerates interested individuals or groups with competing objectives and values for outputs from the resource to participate in the decision-making process. This public involvement includes concerns in the light of the recent UNEP, other global sustainability (e.g. ecolabelling).

Grimble and Chan (1995) propose a methodology that fills the gap by incorporating the stakeholder interests systematically in analysis and policy making and by linking this method with both participatory and macroeconomic techniques. They add, that given existing biases in the access to information, the act of making more information available about the interests, decision framework, and decision-making criteria aids in balancing the power among the interested groups and makes decision making more transparent.

Table 2.1 shows the potential stakeholders that exist in forest management (for example in tree resources) at different levels.

Finally, the objective of modelling forest management problems is to identify and assess possible options, to test the options in different conditions or under different assumptions, and at the same time to provide insights to decision makers, stakeholders and managers for a better decision-making process and improved decisions. Interactive, transparent, and multi-objective decision-making are principal components of long-term industrial forest plantation development at the regional level.

Table 2.1. **Stakeholders of Tree Resources**

Institutional level	Examples of stakeholders	Categories
•global & international •wider society	•international agencies •foreign governments •environmental lobbies •future generations	•biodiversity conservation •climatic regulation •maintenance of resource base
•national	•national governments •macro planners •urban pressure groups •NGOs	•timber extraction •tourism development •resource & catchment protection
•regional	•forest departments •regional authorities •downstream communities	•forest productivity •water supply protection •soil depletion & siltation
•local off site	•downstream communities •logging companies •sawmills •local officials	•protected water supply •access to timber supply •conflict avoidance
•local on site	•forest dwellers •forest fringe farmers •livestock keepers •cottage industry	•land for cultivation •timber & non-timber •access to grasing & fodder •cultural sites

Cited from Grimble and Chan (1995).

The combination of cash flow models and regional forest sector models is incorporated explicitly. Consistency with the economic complexity resulting from the stakeholders' additional circumstances for optimality are considered in this combination.

2.3. **Past Work in Modelling Regional Industrial Forest Plantation**

Figure 2.2 shows representation of the industrial forest plantation planning problem, which can be described as one of developing a forestland allocation plan for each location that maximises some utility or utilities the interest of individuals or groups. Such plans in this case, must take into account the long-term considerations of wood production and cash flows. A critical function of such a scheme is that the financial analysis, forestland allocation, harvest scheduling, and outturn prediction options can be deliberated interactively.

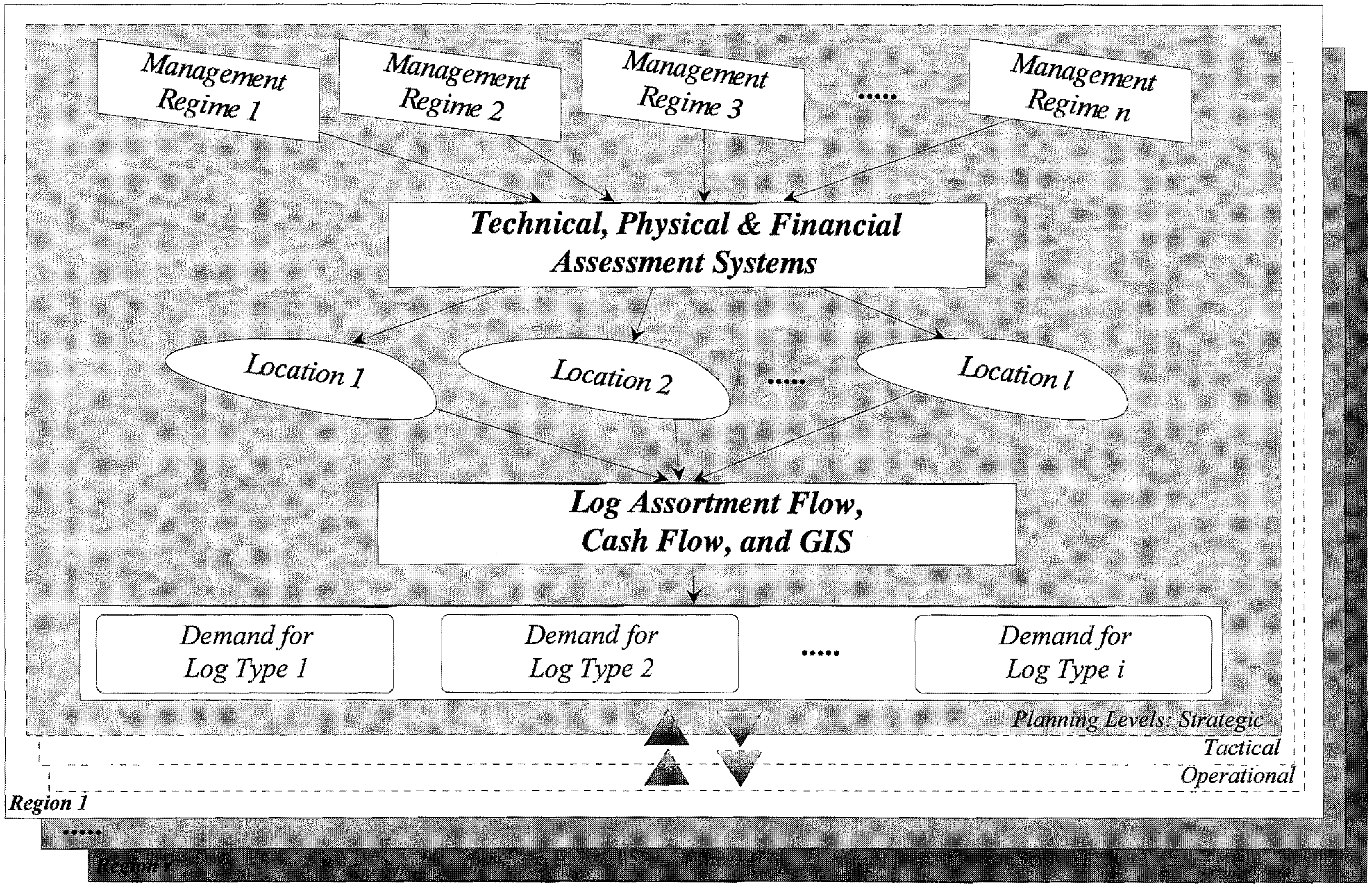

Figure 2.2. Industrial Forest Plantation Planning Problem

For the purpose of this discussion, industrial forest plantation decision planning models in the literature can be categorised three ways, on the basis of the aspects of the industrial forest plantation planning problem that they are formulated to address.

1. Cash flow and economic models;
2. Forestland allocation models, and;
3. Wood supply strategy or forest estate models.

Forest estate model is the term used in New Zealand to describe models for planning the management of forest stand aggregation, i.e. forest estate. These estates might consist of an individual forest or groups of forests at enterprise/local/district, regional, or national levels. In the hierarchy of the forest planning and management systems of Whyte (1991) discussed previously and shown in Figure 2.1 (p.12), these conform to cash flow models, forest estate models and regional forest sector models respectively.

2.3.1. **Cash Flow and Economic Models**

Forest planning is an interative process involving successive approximations of the various relationships considered essential to accomplish organisational objectives. During this initial planning process, formal analysis needs to be able to estimate the plan's likely financial impacts, for example, in regional level of production, allocation of resources, and public budget (Gregersen et al., 1989). The complexity of the interaction between time and uncertainty requires quantitative tools to capture the effects of this interaction on financial performances (Merton, 1995).

Financial analysis is one type of analysis required to estimate commercial profitability for a project. It is carried out from the point of view of certain entities included in the project. Two major financial analysis types used by decision makers are discounted cash flow and internal rate of return (Gregory, 1987). Both require the project's estimated cash flows.

Economic analysis, on the other hand, is needed to convey information on whether or not a project would provide an economically efficient use of the resources available to a community. Mapping the use of these traditional profitability models in deriving information for industrial forest plantation development options and comparing them with long-term models in other sectors helps to create an idea of applicability of the general models in terms of profitability calculations in wood growing development.

In principle, a whole planning system should encompasses a precise statement of possible decision options. Because wood growing is capital-oriented and has certain risk. It, therefore, requires financing which is high in terms of the successive turnover.

Several distinguishing attributes of wood growing activities in forestry (Gregory, 1987) are:

(i) lengthy period of production, for example, under the foremost circumstances Pinus merkusii and Acacia mangium plantations may be available for pulp log cutting after 10 years (Alrasjid, 1984);

(ii) immobility of standing trees concerning stumpage prices which are highly dependent on their specific sites;
(iii) production flexibility (e.g. growth rates and final yields), and;
(iv) ownership.

Extensive and comparative financial and economic analyses of worldwide examples are found in Gregersen and Contreras (1975); Sedjo (1983); McGaughey and Gregersen (1988).

Other local or specific issues related to those analysis include works of Aruan (1990) who developed a spreadsheet-based financial analysis for deriving the minimum economic size for Indonesian sawlog plantations in which IRR and NPV were used extensively; Fox et al. (1989) examine the pattern and magnitude of periodical resource flows, direct, and opportunity costs, associated with implementing forest plans. They consider that these plans may depend on the planning unit sizes. One important feature of their findings is that the basis for allocating targets (for example, volume supplies) to particular units of land has an impact on the outputs of the resources; to some extent the complexity of achieving these output target increases as management unit heterogeneity increases. This underlies the extension of this study. Explanation in greater detail in terms of area size theory and applications is described in section 3.3.1.

Other examples include the following. Pezzey (1992) investigates the concepts of sustainable resource use and sustainable growth in terms of conventional economic analysis. An extensive discussion of the value prediction of shelterbelt investment has been done by Stringer (1984) and Nash (1993) reviews the engine of financial investments in New Zealand forestry. Guidelines for economic appraisal of watershed management projects have been written by Gregersen and Contreras (1976; 1979). Their work has broadened the magnitude of the financial investment information to possible investors in forestry sectors.

The integration or further analysis (comparisons of the profitability) with development options for any management regimes, species and location through optimisation techniques would be a fruitful starting point for delivering long-term strategic development options. This matter is further discussed in the next section.

2.3.2. **Forestland Allocation Models**

As natural forests are continuing to decrease in size and wood supply capacity in most developing countries, the main physical limitation on the future contribution of industrial forest plantation is the forestland availability and capacity questions such as, "*By how much and where forestlands are needed to support the future demand and markets for wood usage?*" (Vaux, 1973) are relevant to the existing and future conditions. The selection of relevant options requires a judgement of how significant, essential or substitutable are the various natural and plantation inputs into the economy (Pezzey, 1992). The way in which the relevant option is translated into a set of conditions for, e.g. future wood supply, is highly dependent on the context. The obvious example such as sustainability conditions might all look be different for different localities or countries over the next decade or century.

Mathematical programming techniques for forestland allocation management planning have included linear programming, mixed integer programming, and goal programming as the main forms (Nautiyal et al., 1975; Bare et al., 1984). It has been almost thirty years since mathematical programming was introduced and applied to forestland allocation management problems. This problem is very relevant to the whole of forest management. This allocation problem like all resource allocation problems has an inherent difficulty of multiple conflicting objectives.

The primary forestland allocation decision is frequently the most important one, not only because of its effect on the physical future wood supply but also because of its effects on the efficiency and flexibility of the plans implementation (i.e. the structure or pattern of the forests) and monitoring processes. One of the earliest linear programming applications for forest management is the work of Curtis (1962). For example, in an early forestland allocation problem, developing forestland allocation plans for each location *l* in region *r*, was reported that linear programming was used. Another early example was by Kent (1980) who used linear programming to develop forestland allocation plans by location and region. Kent (1980) utilised regulation by period in order to develop individual national forest multiple-use land management requirements which integrated land allocation and forest management planning.

For example, in an early forestland allocation problem, developing forestland allocation plans for each location *l* in region *r*, was reported that linear programming was used. In Kent (1980), regulation by period utilising linear programming in order to develop individual national forest multiple-use land management requirements which integrate land allocation and forest management planning. Leuschner et al. (1975) also models multiple-use planning with this application. One of the earliest linear programming applications for forest management is the work of Curtis (1962).

Conflicts over competing forestland uses can be served by, for example, FORPLAN, a large-scale linear programming system for supporting national forestland management planning (Kent et al., 1991). This planning tool is developed as a large single linear programming model which is capable of providing a rational comprehensive approach to developing forest plans. Irland (1985) questions whether or not comprehensiveness in terms of a high level of aggregation is a trap in that planning fails to separate the strategic from the unimportant. The main role in a strategic plan is to define the nature of the plan and the availability of resources. Such a plan is characterised by a highly aggregate level of detail (Gunn, 1991). Table 2.2 indicates the characteristics appropriate to each type of planning level (cited from Gunn, 1991). Therefore, comprehensiveness in terms of detail level is more important in tactical and operational plans where constraints for these two kind of plans are provided by the strategic plan.

Table 2.2. **Characteristics of Planning Problems in Hierarchy**

Characteristics	Strategic Planning	Tactical Planning	Operational Planning
• objective	resource	resource procurement	execution utilisation
• time horizon	long	middle	short
• management level	top	middle	low
• scope	broad	medium	narrow
• source of information	external & internal	external & internal	internal
• level of detail	highly aggregate	moderately aggregate	very detailed
• degree of uncertainty	high	moderate	low
• degree of risk	high	moderate	low

Cited from Gunn (1991).

Major problems of these analytical planning models are (Kent, 1980; Rose, 1984) that:

(i) each objective is evaluated or optimised independently, when simultaneous consideration of several objectives is what really required (multiple objectives);
(ii) the excessive model size for handling national forest planning represented by large number of decision variables becomes unmanageable, and;
(iii) as a consequence of (ii), therefore, data aggregation also causes questions on how and in what way to formulate aggregation classes.

Rose (1984) suggests use of a simulation technique in tandem with or as an alternative to linear programming in forest planning for handling models with a large number of decision variables. Further discussion on the effective usage of simulation and analytical techniques is covered in section 2.2.3.

The other disadvantage of linear programming techniques, i.e. their inability to handle multiple aspects and multidimensional aspects of the planning problem in the forms of the techniques adopted, is a problem that constantly challenges forest planners and managers (Evans, 1984; Glover and Martinson, 1987). The problem is not only the conflict between different uses for limited forestland but also there is a lack of similar perspectives and considerations among the interest groups including decision or policy makers and stakeholders at any institutional level. This planning problem is described in a greater detail in section 3.2.

Land use planners have initiated planning models that are capable of handling multiple objectives (Bare and Mendoza, 1988; 1988a). They identify multiple-use aspects and develop some operational understanding and approaches.

There have been quite a number of multiple objective modelling techniques developed. Many of the works of the 1970s and 1980s have their basis in earlier works (Evans, 1984). McCrimmon (1973), Cohon and Marks, 1975. Hwang et al. (1980) and Evans (1984) provide comprehensive reviews of these techniques. Among major techniques developed to solve multiple objective linear programming problem are:

(i) goal programming (Charnes and Cooper, 1961; 1977);
(ii) maximin and fuzzy linear programming (Dyson, 1980);
(iii) linear goal programming (Lee, 1972, 1973);
(iv) the Step Method or STEM (Benayoun et al., 1971), and;
(v) method of the displaced ideal (Zeleny, 1982).

Techniques to solve multiple objective non linear programming problems, include Sequential Multiobjective Problem Solving Technique or SEMOPS (Monarchi et al. (1973); Geoffrion-Dyer-Feinberg or DGF algorithm (Geoffrion et al., 1972), Zionts and Wallenius method (Zionts and Wallenius, 1976).

Goal programming has been in existence since early mathematical programming. This technique is one of the main analytical tools for developing and dealing with multiple objectives for various sector management planning methodologies such as management in water, agricultural and forestry (including environment), transportation, urban systems, electricity, and industry (Cohon, 1976; Loucks, 1977; Ignizio, 1980; Merril and Schweppe, 1984; Tecle et al., 1989; Suter and Calloway, 1994; Bowerman et al., 1995). Goal programming has became a powerful decision making tool with its methodological limits and powerful boundaries (Schniederjans, 1995).

Two variants of goal programming technique, i.e. MINMAX and MINSUM formulations (Daellenbach et al., 1983), are described in detail in section 3.2.3. A survey of goal programming was provided by Kornbluth (1973). This technique was first introduced to forestland management planning applications by Field (1973). Other application examples are the works of Bertier and de Montgolfier, 1974; Bell, 1975; Bottoms and Barlett, 1975; Nautiyal et al., 1975; Schuler et al., 1975, 1977; Dress et al., 1975; Dane et al., 1977; Arp et al., 1982; Mendoza et al., 1986; Rustagi et al., 1987; Mendoza et al., 1987; Bare et al., 1988a). Schniederjans (1995) provides a comprehensive bibliography of all goal programming publications in a range of aspects.

Various supplementary refinements to goal programming in forestry applications have been carried out. These include the works of: Bare and Mendoza (1988) who use *de novo* programming in forestland management planning to not simply optimise a given system but to lay out an optimal system; Brill et al. (1982) who developed the Hop, Skip, and Jump (HSJ) technique for the purpose of handling the complexity and the qualitative nature of public sector planning problems; Mendoza (1986) who proposed a heuristic programming for dealing with estimating efficient targets in order to improve computational efficiency.

Those methodologies tried to captured the real world complexities of the forestland allocation planning problem. Although further multiple objective formulations may materialise, any that would be suited to modelling this planning problem effectively need to incorporate other supporting techniques such as measurement of financial, economic or production goals. This incorporation gives more useful and meaningful solutions. For example, Chang and Buongiorno (1981) state that although all the studies of multiple use planning referred to yield solutions that minimise the deviations from the goals according to the priority and or weight distributed to their goals, they fail to take into account both the actual inputs (such as labour and budget inputs) and inputs from other management activities. This failure does not include the work of Bottoms and Bartlett (1975), who propose an integration between goal programming and input-output analysis to handle this aspect in order to help forest managers plan their operations yearly. Overall, the direction of those applications should consider the direction and control issues which should remain with the decision makers and not with the method (Buchanan, 1994).

Finally, those multiple objective decision making applications with their strengths and weakness can be reviewed to ensure that chosen objectives are:

(i) included and represented in the model;
(ii) scrutinised and questioned regarding their importance, and;
(iii) given appropriate weights and units to provide meaningful results.

2.3.3. **Forest Estate Models**

Major efforts in forest management modelling towards sustained wood and other non-wood outputs include the work of Whyte (1991), Dykstra (1990), and Tait (1987). Their work considered mainly managing forests to ensure the flow of a sustained wood supply and other products. These models are classified as simple dynamic models because the way that they are formulated for calculating a rotation that maximises production from a specific forestland in infinity does not estimate the technical requirements of the wood processing sector. There are two causes: firstly, no constraints are forced upon volume production in the model, and secondly, there is no log assortment desegregation (Gunn and Rai, 1987; Whyte, 1991). These two features are important factors for processing or utilisation planning.

With simple dynamic models, optimal management strategies for each stand within an estate can be reasonably easily calculated with correct yield predictions in the case of maximising total volume production or revenues being the factor of attention with no consideration to be given to the wood processing sector. Furthermore, most forestry companies experience various constraints not only on production itself (i.e. total volumes and/or revenues) but also with the log assortment composition, and irregularity or regularity and timing of their individual commitments to supply wood to their processing plants.

The usual randomness of the age class distribution within a forest or forests and the various requirements of the processing plants by log assortment specifications, requires a broadening of stand prescriptions from simple dynamic models to whole forest estate models. Simple dynamic models are, accordingly questionable with regard to their optimal solutions; for example, de Kluyver et al., 1980. The input and output flows from a forest estate apparently vary extensively, for example, as a consequence of chosen species combination and forest estate age formations which are inappropriate from a wood processing viewpoint. The other drawback is that insufficient information is provided to managers to constrain production. Adequate information appropriately modelled can help decision makers stabilise wood supply to meet targeted markets. In addition, sufficient information allows managers to select derived options that best fulfill their objectives. Forest estate models are now the primary basis for harvest and regeneration planning systems.

Allison (1986) states that forest estate models have emerged as the modern form of forest plans by incorporating the advantage of increasing computer power. New Zealand's large exotic forests are characterised by:

(i) the irregular age class distributions, and;
(ii) species and silviculture treatment mixtures.

These two combinations are leading factors in the formulation of New Zealand forest estate modelling systems (Shirley, 1979).

Forests can be regarded as forest stand aggregations which can be at the local forest, regional, or national levels (Garcia, 1990). Forests can also be regarded as forest crop type aggregations. In New Zealand, these crop types are utilised as the basic unit of forest estate description. These crop types are defined as areas of trees uniform for all practical purposes of description and management (Allison, 1986). A single crop type would be expected to follow the same management schedule and yield curve and may consist of several different stands which are different ages. Forest estate modelling techniques are predominantly based on either:

(i) simulation as in Allison (1986), Garcia (1981), and Jamnick (1990), or;
(ii) mathematical programming (especially linear programming) and related techniques as in Johnson and Scheurman (1977), Barros and Weintraub, 1982, Gunn and Rai (1987), Garcia (1984; 1990), Kent et al., 1991, and Laroze and Greber (1991).

In optimisation models the relationship between the elements of the system are expressed via mathematical formulations whereas in simulation models, relationships are represented using an algorithm encoded in a computer program (Hoover and Perry, 1990). Simulation models are utilised to develop adequate forest management strategies through an iterative (or trial and error) process while optimisation models are used to determine those management strategies which evaluate all possible feasible solutions through an objective function that can be maximisation of volumes or revenues or minimisation of costs which satisfies a set of physical constraints (e.g. capacity on volume production by period, minimum harvest level, minimum or maximum area availability, transportation distance, equipment, *etc*), financial constraints (e.g. budget for planting and harvesting), or other types of constraints. Allison (1979) states that optimisation does provide the means objectively to choose on the basis of a single objective function which must also be chosen for maximising although many objectives would be taken into account. In addition, there might be some doubt as to the rationality or relevance of the objective chosen.

Nevertheless, both optimisation and simulation techniques should be considered as complementary tools, where the magnitudes of solutions from optimisation models can be explored in detail by simulation models (Whyte, 1991). In other words, both simulation and optimisation techniques should be developed together in order to provide a practical forest planning methodology. These model forms should be (Elliot, 1979):

(i) accessible;
(ii) understandable by the users;
(iii) simple to use;
(iv) flexible;
(v) able to be undertaken to represent the current condition of the forest estates and at least able to predict future availability of wood supply and forest estate structure;
(vi) able to model a variety of forest operations, and;
(vii) structured to allow these operations that must be applied to meet given requirements to be identified.

A recent example is IFS, the simulator, (Garcia, 1981) which can share inputs and outputs with FOLPI an optimiser (Garcia, 1984). Detailed linkage application development between RMS-2020 (Allison, 1989) and FOLPI (Garcia, 1984) is described in section 3.3.3 as part of the research reported here.

Irregularities in age classes nowadays are the emphasis on efficient forest estate management. Two classic forms of harvest scheduling LP-based model formulations were developed and they have been recognised as model I and II formulations (Johnson and Scheurman, 1977). In model I, an activity refers to a complete set of management prescriptions over a land area for the entire planning period whereas in model II, an activity refers to a complete set of management prescriptions over a land area only from the period the stand is regenerated until it is harvested. The stand identity is not preserved after a regeneration harvest in model II but in model I, this identity is preserved and can be divided and combined with other management units after harvest. The stand identity can be considered a disadvantage for model II formulations (Gunn and Rai, 1987; Barros and Weintrub, 1982). In intensive plantation forestry, neither of these two models is of much practical relevance.

Garcia (1990) describes a third model formulation more suited to intensive management. It is an algebraic representation of a network model, which overcomes the limitations of model II by allowing the stand identity to be maintained. Model III allows greater flexibility in the modelling of management prescriptions than the previous two model formulations. Examples are works of Garcia (1984), Reed and Errico (1986), Gunn and Rai (1987), and Davis and Martell (1993). Greater detail is examined for FOLPI (Garcia, 1984) which is a base for this third model formulation. However, Garcia (1990) states that these three model formulations are essentially equivalent in their power for describing forest planning problems but they contrast in their applications and usefulness.

Whyte (1991) mentions that many forest management and harvest scheduling decisions are influenced not just by technical and operational aspects but also more by political and other such factors that are not part of any formal quantitative approaches. Such factors can create a lack of confidence in those chosen models and adversely affect progress towards an improved quality of decision-making in forest management (Whyte, 1991; Elliot, 1979).

In all these forest estate model formulations, strategic management prescriptions are usually specified by aggregations of crop type and log product classes. These go far in describing the physical outputs of a forest. However, there are limitations with such models. For example, forestland available for further industrial forest plantation extension or development in the long-term is not particularly well addressed. Two major inadequacies in those models are:

(i) a lack of mechanism for evaluating possible forestland ability and capability, and;
(ii) a lack of an interactive mechanism and transparency in the decision-making process.

These deficiencies refer to long-term periods and at regional levels, and they are, therefore, part of the central focus of this study.

2.4. **Summary**

Extensive studies have already been conducted for industrial forest plantation planning problems in the published literature. Studies have focused mainly on development of models in order to aid in decision making for components of:

(i) the financial or investment decision support systems which include investments for plantation establishment and harvesting;
(ii) forestland allocation, and;
(iii) long-term management planning strategies.

These have resulted in the development and adoption of a variety of modelling techniques. Those various techniques are successful and extensively used in various forestry sectors worldwide - forest resource-based, forest products industries, and forest marketing.

However, the integration of those components for long-term strategic planning should allow inherent problem-solving of forest management problems; that is, holistic decision-making processes at the regional level should include transparent, interactive, and integrated planning systems. This requirement has received relatively little attention in the published literature. An important role in the development of industrial forest plantation long-term plans is performing integration of financial analysis and forestland allocation planning methodology on the basis of interactive decision-making processes. This integration would involve vertical and horizontal management-level. Solutions from the methodology should specify investment options selected for different management regimes, species, and locations.

Those solutions also determine the opportunity to allow trade-offs between derived options by being a transparent and interactive planning system and acceptable to various interest groups and decision making levels.

These techniques and tools which already exist and could be made available in the near future need to be brought to the attention of those engaged in this kind of decision-making. Three major improvements, however, are improving the information flow from information sources to analytical required tools, simplifying the development and purpose of analytical tools, and making the solutions more effective (Gilbert, 1988).

Finally, it is still a valid question to determine "*from the public economic interest, how much land is needed to provide timber supply for the future?*" (Vaux, 1973). Adaption of this question in today's context might be "*from the public economic interest, how much forestland is needed to provide commercial and non-commercial products for the future?*", so that consistency in planning systems needed can be utilised.

Chapter 3. The Integrated Regional Planning System

Not every end is a goal. The end of a melody is not its goal;
however, if the melody has not reached its end, it would also not have reached its goal.
(F.W. Nietzsche)

A detailed description of the integrated and interactive planning system which is proposed for modelling of options for industrial forest plantation development plan is now developed. The proposed structure involves six sub-models. The sub-models are developed and solved, particularly to illustrate forestland allocation and multiple outputs from multiple objectives. These steps are based on the interactive planning prototype. An overview of planning systems in general, strategic options, multiplicity of objectives, the spreadsheet-based model capabilities, and the proposed MODM planning framework are presented in Sections 3.1. and 3.2. A detailed description of an integrated regional planning system for industrial forest plantations is described in Section 3.3.

Underlying the decision-making process is an interactive description method which is utilised to define the interactive and transparent aspects between the decision makers and the stakeholders or public. A spreadsheet-based model was developed in this study for deriving the minimum economic size for selected management regime and species, and also for linking forestland allocation models at the crop type level. This is described in Section 3.3.1. The forestland allocation model is described in Section 3.3.2. In Section 3.3.3, a link between established optimisation and simulation models in obtaining the proposed deliberated options is presented. The last two sections, 3.3.4 and 3.3.5, incorporate a proposed GIS and a discussion of data requirements for the integrated planning system respectively.

3.1. General Considerations

In industrial forest plantation planning systems, a wider analysis would encompass the broad options of all forest products from the forests.

In considering the whole range of benefits arising from industrial forest plantations, that it is complicated:

(i) to determine monetary and non monetary values for many of costs and benefits or revenues implicated. The techniques quantify these values are shown in section 3.3.2.2;
(ii) to compare the management options with that of alternative form of forestland use (in terms of space or landscape and time), and;
(iii) to ensure a fair distribution of costs and benefits that would provide sustainable management a competitive proposal compared to other investment options (FAO, 1993).

3.2. **Strategic Planning for Industrial Forest Plantation - Several Options**

A key part of the strategic planning process is to ensure establishment and formulation of strategic options, and setting and reviewing objectives (Dyson, 1990). When a strategic option for industrial forest plantations is implemented, it may be difficult to reverse the decision, and so the planning process must involve careful evaluation of options and future influences at the outset.

MODM is an approach devised to assist the planning process for deliberating options which correspond to values in cases characterised by multiple, noncommensurable and conflicting criteria (Bogetoft & Pruzan, 1991). MODM is generally concerned with the rational elicitation of human value judgments as its philosophical key (Stewart, 1994). This approach involves searching to make the DM's (decision maker's) evaluation as effective and efficient as possible, and to maintain some degree of consistency, or at least warning to the DMs of their inconsistencies (Stewart, 1992). Furthermore, a communicative decision process should be expanded and elaborated to offer a broader perspective.

The next two sections deal with these issues. A further section covers spreadsheet capabilities which are especially useful in handling the modelling of financial analysis and optimisation.

3.2.1. **Multiplicity of and Conflicting Objectives**

A fundamental concept that reflects the decision-making process generally assumes the need for decision-maker(s) to undertake careful consideration of various viewpoints through evaluating the set of possible actions.

In planning at the regional level, economic development addresses a highly interwoven set of:

1. social objectives, e.g. quantitative and qualitative elements of living standards like level of subsistence for labour force, incomes, revenues, etc;

2. spatial objectives, e.g. location and distribution patterns, transport network; and;

3. environmental objectives, e.g. ecological quantity and quality (Rietveld, 1980; Andersson & Kallio, 1986).

These decision problems may be more difficult to solve due to their complexity and the incommensurability of decision criteria (Rietveld, 1980). D'silva et al. (1994) summarise five conflicting goals which must be balanced in sustainable forest management in most developing countries:

(i) economic importance;
(ii) social goals of the local people;

(iii) environmental goals for forests;
(iv) recreational goals for forests; and;
(v) international goals (e.g. there may be a constituency willing to pay for maintaining tropical forests for biodiversity).

The conflict, among these profound goals develops the pressures on the forestland allocation and use (*ibid*).

Decision problems involving the environment are very difficult to deal with. Two important difficulties are the complexity of systems and imprecision of data (Bertier & Montgolfier, 1974). The ecological issues have to be regarded in any suitable systems analysis (Baumol & Oates, 1975; Krutilla & Fisher, 1975; Clark, 1976). In addition, consensus in the decision-making process may be difficult to achieve even when those conflicting objectives are addressed simultaneously (Whyte, 1995).

The land-use planning process is concerned with the combined protection, production and utilisation of land at a given location. Land allocation becomes an important matter when those combined and varied needs are urgently required simultaneously in, for example, supplementing wood from plantations, improving living standards, and reducing soil erosion. Various decision problems in which a single option must be determined from many potential options involve a multiplicity of objectives (Rietveld, 1980; Bogetoft & Pruzan, 1991). Evans (1984) gave three reasons for the increasing attention towards multi-criteria decision making:

(i) most decision problems are inherently multi-objective;
(ii) numerous stakeholders exist and are involved in many facets of the problem, and;
(iii) there has been much improvement in computing capability.

Multiple objectives may be categorised in different ways. One such way is to classify multiple objectives into those which are (Bogetoft & Pruzan, 1991):

(i) inherent (or natural) to planning problems;
(ii) protection against oversimplicity of the problems, and;
(iii) analysis extension.

Multiple objectives often mean multiple conflicts. This multiplicity and non-commensurability of objectives is to be optimised simultaneously. MODM is concerned with this circumstance.

According to Brill (1979) the multiplicity of objectives can be related to the level of completeness that a model captures in a particular problem. There are several limitations to using either complete or incomplete multi-objective models. A complete multi-objective model captures all the issues applying to a particular problem, whereas an incomplete model addresses only partial issues and analysis related to a problem. In explaining limitations to the use of complete and incomplete multi-objective models, he notes that complete multi-objective models:

(i) are impractical computations for many objective functions in generating a comprehensive set of tradeoff relationships, i.e. the non inferior set, and;
(ii) create difficulty in comprehending and communicating important tradeoffs.

On the other hand, limitations in using incomplete multi-objective models include:

(i) difficulties in accomplishing comprehensive representation of a planning problem, and;
(ii) partial analysis possibly leading to different best solutions which may lie in the inferior region.

In order to balance the above issues, a forestland allocation planning problem in this study attempts to focus on multiple objectives and goals so that increased assorted log production, improved water quality and soil protection, and increased recreational and wildlife management opportunities can be generated (Arp & Lavigne, 1982; Bare & Mendoza, 1988). Furthermore, complex inter-relationships among those objectives, goals, decisions and extensive data relevant for the comprehensive decision-making process tools facilitate the opportunity to use complete and analytically oriented devices such as MODM.

Regional planning, which is directed towards achieving goals prepared for a specific spatial location, proposes ways of integrating various policies and their conflicting objectives. The way in which formulations of priorities and preferences among those objectives are modelled is an important part of the entirety of a planning process (Rietveld, 1980). The conceptual framework for MODM problems presented in Figure 3.1 shows the decision framework in forestland allocation which is appropriate for this multiplicity of objectives development. This figure demonstrates four development options for industrial forest plantations that can be considered to be more appropriate than those usually occurring.

This conceptual framework also tolerates flexible formulations in dealing with weighting or prioritising between conflicting objectives such as:

1. considering several relevant criteria including guidelines. For example, ITTO or current regulations) and codes of practice;

2. involving more active public participation by local communities or NGOs and through which participation can play more open and significant roles in, for example, diagnosing social problems, organising local communities, and evaluating forestry projects;

3. catering for an inter-departmental working group, for example among land-based operations (e.g. forestry, mining, agriculture, transmigration, fishery, and transportation).

But Figure 3.1 would not be complete enough to provide a framework for an answer. It should be extended in order to allow for the problem-solving character of the decision-making process including, for example, analytical, communicative, evaluative, dynamic, and available resources.

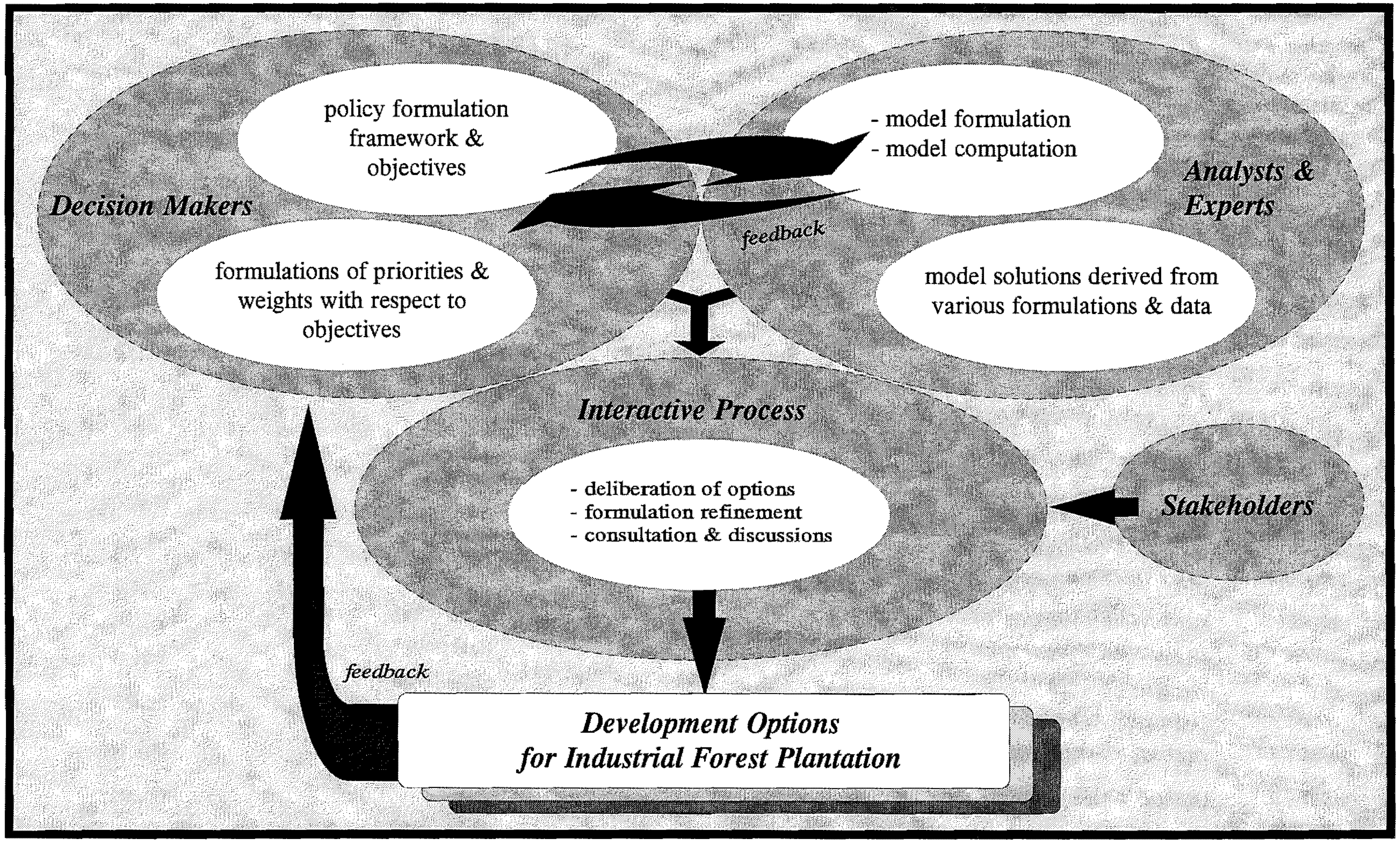

Figure 3.1. Decision Framework in Forestland Allocation

3.2.2. Communicative Decision Process

The communication aspect of a decision process is important to successful decision-making. This activity can be more than just technical communication between decision makers, analysts and stakeholders.

Bogetoft & Pruzan (1991) explain the context and purpose of MODM and which parts of the model represent activities for communication. Furthermore, they indicate that these activities need both decision makers and analysts to generate interactive discussions.

Analysts working with decision makers also contribute different important feedback possibilities in policy formulation and both the formulation and computation of the model (Ritveld, 1980). Whyte (1991) offers a different perspective of communication, that an uneasy segregation between research and management may be a factor in promoting lack of consensus. In addition, a lack of explicit and meaningful discussion at any level of the forest planning process could prevent explicit decision-making and lead to unnecessary development.

Improved communication between decision-makers and analysts is required. Conflict among objectives, moreover, results in not all objectives being fulfilled simultaneously, although feedback of, for example, uncertainty regarding the requirements, may produce better options.

These options would be conveyed within an interactive process where the stakeholders - managers, owners, dwellers, decision-receivers - will be actively involved in any level of the decision-making process (Figure 3.1). This interactive process involves: (i) deliberation of options; (ii) refinement of formulations, and; (iii) consultation and discussion.

Thorough consultation and discussion would generate feedback that can assist decision makers to reformulate priorities and weights with respect to multiple objectives. Then, analysts and experts would reformulate and recompute models in order to derive preferred, deliberated solutions from various data and formulations.

Whyte (1995) emphasises an extension of his 1991 concern to provide tools that allow managers to cope with political considerations and the need for a participatory decision-making process. He summarises the specific aims as follows:

- consider the meaning of sustainability;
- deduce the implications of this meaning for resource managers;
- review relevant data and criteria for assessing sustainability;
- outline an interactive modelling framework that is appropriate for participatory decision -making to meet multiple objectives;
- indicate appropriate standards for monitoring managerial performance and reporting on the sustainability of outputs, and;
- provide illustrative examples to compare and contrast the methodology recommended here with other approaches.

Other features of the communicative decision process are the levels of transparency and interaction required when adapting the recommended approach to explore solutions in order to acquire insights into the interactions among tradeoffs (Whyte, 1995). Bogetoft (1986) states that there are three general characteristics of communication:

(i) the types of information exchanged or price interpretations;
(ii) the organisation of communication, and;
(iii) the quality of the communication.

This communicative consideration was applied in order to select the MODM methods and is described in section 3.2.3.

The types of information exchanged or price interpretations allow resource indications to be understood. Tradeoff, price or dual values are resource indicational examples. The effect of these indications (or signals) is to give assistance to decision makers and analysts in their search for compromise solutions (Bogetoft, 1986).

The second characteristic is the organisation of communication, that is how the decision makers and analysts express their responsibilities and interactions. Bogetoft (1986) provides the general communication diagrams as shown in Table 3.1.

The mathematical set considered is:

$$\begin{array}{ll} Max \;\; F\,(f_1(x),\ldots,f_n(x)) & x \in X \\ Max \;\; F\,(y) & y \in Y\,; \quad Y \doteq (y_1, y_2, \ldots, y_n) \end{array}$$

where: F: *basic decision problems*

Y: *the set of feasible solutions*

Table 3.1. **General Communication Diagrams**

	DMs learn about Y	Analysts learn about F
• resource (R)	① *DM-R procedure* DMs *decision* ↓ ↑ *substitution* analysts	③ *AN-R procedure* analysts *decision* ↓ ↑ *substitution* DM's
• value (V)	② *DM-V procedure* DMs *substitution* ↓ ↑ *decision* analysts	④ *AN-V procedure* analysts *substitution* ↓ ↑ *decision* DM's

Cited from Bogetoft (1986).

The assumptions are:

(i) DMs understand the basic decision problem (F) and analysts know about the set of feasible solutions (Y). In maximisation problems, resources provide information about a given point or imposed constraints on the set of points to be estimated, whereas values express a willingness or a possibility to substitute between different criteria values (Table 3.1);
(ii) both DMs and analysts are able to investigate F and Y in order to answer their inquiries about F and Y; inquiries are about DMs' most preferred point in Y' when solving maximisation $\{F(y) \mid y \in Y\}$, and;
(iii) F may not change during the communication process, and (iv) in maximisation problems, DMs prefer larger to smaller values in each feasible solution ($Y = (y_1, y_2, \ldots, y_n)$).

Table 3.1 quadrant ① represents DMs learning about Y (DM-R procedure) by searching the set of possibilities through imposing varying resource (R) constraints (Benayoun et al., 1971; Rietveld 1980) whereas quadrant ③ represents analysts (ANs) learning about F (AN-R procedure) by inquiring for direct information about the DMs' objectives around a given resource point (Geoffrion et al., 1972; Musselman & Talavage, 1980). Quadrant ② represents DMs learning about Y (DM-V procedure) by varying values of weights of importance distributed to the different objectives by either priority goal structure (Lee, 1972) or by reference point (Wierzbicki,1979) while quadrant ④ represents ANs learning about F by asking the DMs to evaluate existing value substitution possibilities (Zionts & Wallenius, 1976; Steuer & Choo, 1983).

Many MODM techniques vary from the above communication diagrams: for example, both DMs and analysts simultaneously determine the basic decision problem (F) and the set of feasible solutions (Y) such as the MODM model has been developed and adopted in this study which is a combination between DM-R and AN procedures (Table 3.1. quadrants ①, ③ and ④ respectively).

The third characteristic is the communication quality. Communication quality should facilitate both the mathematical aspect and the final decisions. The mathematical aspect is not usually the most important factor but is usually only a minor part of the total effort required in solving real problems (Wagner, 1963). The effort is to utilise MODM techniques to bring about improved solutions toward the final decision.

Stewart (1992) emphasises that MODM provides:

(i) a valuable means of understanding the problem structure prior to decision analysis (when a large number of or even infinite possible decision alternatives/options are able to be reduced for searching the *best* solutions), and;
(ii) sufficient assistance for DMs' confidence in making a final choice.

The decision making process can be thought of as involving data gathering and analysing. Managing this planning system for industrial forest plantation development requires access to enormous quantities of standard data of various types. In this planning system information such as forestland resources, crop type production and harvesting, environmental, and social data must be collected, sorted, and utilised. In addition, especially for data collection, the orientation should be toward holistic mechanisms and integrated regional data collection, plantation management, and monitoring steps.

The last two sections provide theoretical insights into the interaction between the decision-makers, analysts (and experts), and stakeholders involved in MODM. The next section explains the more practical and applicable MODM approach for a forestland allocation problem.

3.2.3. **Multi-Objective Decision Making (MODM) Methods in a Theoretical Planning Framework**

In practical circumstances, many decision-making problems cannot be analysed adequately without taking into account multiple objectives. It appears to be infeasible to find a solution in which all objectives are fulfilled optimally. An optimal solution for one specific objective generally leads to poor achievement for the other objectives (Rietveld, 1980).

Thus multi-objective decision-making has been set up as a sub-discipline within operations research (OR). Much has been written over the last two decades on the subject in many textbooks and in other technical contributions. Hwang et al. (1980) provide an extensive MODM tutorial. Other MODM reviewers are Cohon & Marks (1975), Ignizio (1980), Widhelm (1980), Roy & Vincke (1981), Zeleny (1981), Evans (1984), and Romero (1986). In forestry applications were described in Section 2.1.

Whyte (1995) concludes that few such contributions appear to have referred to holistic sustainability problems. But the widened sustainability concept has become the most important forest management issue during the last decade. In this regard, he suggests a need to explore more fully how to analyse MODM problems, involving endless combinations of weights. In addition, other dimensions, such as a decision maker's confidence in the solution acquired, ease of use and understanding of the method, usefulness of information provided, and rapidity of convergence (Wallenius, 1975) need to be addressed.

A precise set of definitions in planning and mathematical programming is absolutely essential. The following definitions are based on those given by FAO (1974a); Ignizio (1983); Vaux (1968):

Planning is the process of working out how to achieve an objective or objectives in practice.

Objective is political statement of intention formulated by governing groups and represented by mathematical functions of their decision variables.

Goal is an interpretative representation of objective in physical and quantitative terms, which specify a state to be achieved at some future date or state to be maintained over a specified time period.

Policies or *Strategies* is mean of achieving objective and goal.

Constraint is restriction imposed to ensure better realism in the systems being modelled.

In some terminology, goals and objectives are reversed in the nomenclature system.

Three standard characteristics of MODM methods possess (Hwang & Masud, 1979):

(i) a set of quantifiable objectives;
(ii) a set of defined constraints,and;
(iii) a process of obtaining some tradeoff information.

There are different approaches to deal with MODM problems and they can be categorised roughly into three groups: weighting methods; interactive solution methods; and sequential elimination methods (Daellenbach, et al., 1983) or alternatively in two groups; mathematical programming and spatial proximity methods MacCrimmon (1973). Daellenbach's is the one adopted here. The classification is not exact since many of the approaches could fit into more than one category (Evans, 1984).

The characteristics of the first group (weighting methods) are:

(i) an infinite or a large set of available options with specified objectives and objective values with specified constraints for objectives;
(ii) a process comparing objectives by obtaining numerical scalings of objective values (intra-objective preference) and numerical weights across objectives (inter-objective preferences);
(iii) an objective function, either global (goal programming) or local (linear programming), and;
(iv) rating the alternatives on the basis of the highest weight. In this method the decision maker is able to define tradeoff relations between objectives which allow the aggregation of the objective values associated with an option into a single number which considers the option's overall desirability. As examples, the GP model and its variants (linear, non-linear or integer GP) are widely applied MODM methods.

The second group (sequential elimination methods) has several characteristics such as:

(i) a set of available options with specified objectives and objective values;
(ii) order across objectives;
(iii) a set of constraints across objectives, and;
(iv) a sequential comparing process for options on the basis of objective values so that options can be eliminated or not.

Unlike the weighting method, this method does not allow trade-offs between objectives because this method relies intensively on the existence of alternative optimal solutions to achieve any of the lower priority objectives. Pre-emptive GP models and lexicographic models are examples of this method.

The third group (interactive methods) has two characteristics, namely:

(i) a finite or large set of options with a set of objective constraints, and;
(ii) tradeoffs which are the input in an algorithm finding new solution, then later repeating the submission of this new solution seeking new tradeoffs until the preferred solution is accepted. Special algorithms for solving MODM problems are incorporated into specific methods such as STEM (Benayoun et al., 1971) or Zionts-Wallenius method (Zionts & Wallenius, 1976).

The main characteristics that are considered for selecting appropriate MODM methods are (Hwang et al., 1980; Tecle et al., 1988):

1. the regional industrial forest plantation management problem is considered to be inherently a multiple objective problem that requires analysis using MODM methods in order to achieve its management programme. In other words, characteristics of the planning of industrial forest plantation development systems would be responsive to multiple objectives such as to production itself, to environmental impacts (conservation), to socio-economic aspects of local communities, to the economic system which generates the revenues to the organisation, to the technical system which affects planning decisions and so on;

2. the solution algorithm for the given problem can be solved in deterministic form in terms of handling an infinite number of options (crop type as a function of location, management regime and species) and as a large scale problem, and;

3. the level of DM and/or analyst involvement is to the extent which the DM's desire to involve and interface, while analysts/experts are needed for developing the model formulations and deriving their solutions, ensuring ease of use and coding, and providing simple and useful information to assist the decision maker in order to improve the quality of the decision making process.

The above technical considerations suggest that the concept of GP is easily understood and that its algorithm is able to explore and allow all possible compromised solutions which results in sacrifices via trade-offs of some objectives. In addition, the translation of inputs to the DM and public should be transparent because the nature of the decision-making process in industrial forest plantation management needs to be interactive. Thus, this quantitative method (GP) provides possibilities for enhancing discussion and consultation among interest groups.

Thus, goal programming (GP) is one of the weighting methods that can be used, the term having been proposed by Charnes & Cooper (1961) for a special kind of mathematical programming formulation that employs certain conditions which are characterised as "*goals*" to be satisfied "*as closely as possible*". In LP problems the objective function traditionally is the highest priority goal, and constraints are met as lower priority goals. The latter often lead to infeasibility. In contrast, GP simultaneously considers each criterion in the optimisation process to overcome infeasibilities (Kao & Brodie, 1979). As suggested by Charnes & Stedry (1966) the GP formulation applied to corporate modelling overcomes one LP fallacy, namely the existence of one all-important objective function. In addition, the GP method requires the decision-maker to set goals for each attainable objective (Hwang et al., 1980).

In general, GP can be utilized to model situations in which, according to Kornbluth (1973) and Stewart (1992):

1. objectives can be expressed as desired values for goal variables;
2. achievement of objectives depends upon the values taken by policy variables under the control of the decision maker;
3. the policy variables are constrained by a series of linear relationship;
4. the decision maker has made some subjective weighting concerning the importance of goals, and;
5. the number of objectives is large (greater than about 10).

On the other hand, GP is criticised for subjectivity when applying priorities to the various goals (Cohon, 1978). Therefore, although the use of GP in dealing with MODM problems may be valuable in generating insights for the decision makers, it should be realised that an optimal solution to the MODM problem can be provided only in restrictive special cases. Zeleny (1981) discusses the strengths and weaknesses of GP, while Hannan (1985) discusses some criticisms of it. The consensus appears to be (e.g. Dykstra, 1984), that these difficulties can be overcome if recognised fully and if the tool is used properly, i.e. to aid decision-making, not make them.

This study provides a simpler alternative to understanding and manipulating MODM problems as they relate to forestland allocation. It should be noted that this study is not undertaking a criticism of classical methods nor emphasising that the latter do not have advantages. This study emphasises the positive aspects of proposed options that can be revealed. Attention given in this study emphasises the extension of MODM tools into decision making for a group situation, especially where there are considerable inter group value and preference conflicts.

These groups are categorised as policy and decision making institutions (i.e. Ministries of Forestry, Industry, Finance, Internal Affairs, Trade, Environment, and Transport), enterprising institutions (local or private forest enterprises) and local communities (forest dwellers, transmigrators and local people). These groups have their intra groups' and inter groups' interactions. Interactions are:

(i) intra institutional (due to institutional structures, for example, in the Ministry of Forestry with top, middle and bottom management);

(ii) inter forest enterprise (where ownership, business orientation and size are distinctive);
(iii) inter local community (where different native groups, customary rights, public values and perceptions occurred), and;
(iv) between institutions, e.g. Ministry of Forestry, Ministry of Transmigration, Ministry of Mining, *etc.*

Consensus among decision makers has long been accepted as a desirable outcome of group decision making (Quinn, 1980; Whyte, 1989). Further research on decision making in groups and incorporating consensus which may serve to clarify important relationships should be carried out. However, this entire planning system:

(i) contributes similar starting points which allow interest groups more willingness to openly discuss due to confidence through a quantitative, interactive and transparent decision making processes, and;
(ii) provides a consensus-seeking decision-making framework for the development of the industrial forest plantation plans.

GP is a methodology that works on a conversion of the baseline model (Ignizio, 1983). The general form of the baseline model is to find x so as to:

$$\begin{array}{lll} \text{maximise:} & f_r(x)\ \forall\ r & r = 0,\ 1,\ 2,\ \ldots \\ \text{minimise:} & f_s(x)\ \forall\ s & s = 0,\ 1,\ 2,\ \ldots \end{array} \qquad (2)$$

subject to:

$$f_t(x) \begin{pmatrix} \le \\ = \\ \ge \end{pmatrix} b_t\ \forall\ t, \quad x \ge 0 \quad t = 0,\ 1,\ 2,\ \ldots \qquad (3)$$

x: variable	s: minimisation
r: maximisation	t: equality

The transformation is to convert all the objectives in (1) and (2) directly into goals as target *constraints*:

$$\left.\begin{array}{c} \textit{maximised} \\ \textit{minimised} \\ \textit{equal} \end{array}\right\} \textit{objectives} \begin{pmatrix} f_r(\bar{x}) \\ f_s(\bar{x}) \\ f_t(\bar{x}) \end{pmatrix} \text{ are converted into goals : } \begin{pmatrix} f_r(\bar{x}) \ge b_r \\ f_s(\bar{x}) \le b_s \\ f_t(\bar{x}) - b_t \end{pmatrix} \qquad (4)$$

The characteristics of various types of GP relate to the goodness measurement of value of x to goals (Ignizio, 1983). Some goodness measurements include (Ignizio, 1983) the following.

1. The ability to minimise a sum of weighted goal deviations, which approach is known as the MINSUM formulation in GP. This measurement is classified as the Archimedian form of discrepancy and is a variation of the additive preference function (Stewart, 1992). Furthermore, the concept of trade-off is the principle in this interpretation of this additive value function (Stewart, 1992).

2. The ability to minimise some nonlinear function of goal deviation variables by using exponents to emphasise the importance of one goal relation to the others rather than weighting coefficients.

3. The ability to minimise the maximum goal deviation, namely, the MINMAX approach. Another classification is a Tchebycheff discrepancy form (Stewart, 1992).

4. The ability to develop the lexicographic minimum of an ordered set of goal deviations, or a set of weighted goal deviations, categorised as a pre-emptive priority structure or pre-emptive discrepancy form (Stewart, 1992).

5. the ability to develop a set of non-dominated solutions within the 'neighbourhood' of the initial solution as derived by any of the above approaches.

In GP the optimising criterion is to minimise some suitable metric for the distance from the ideal solution or as desirable targets to aim for (Daellenbach et al., 1983). The difference s_i between each target and the actual obtained goal level illustrates the amount of underachievement or overachievement for goal i (G_i). As shown in equation (5) target constraints can be expressed as fractional deviation equations:

$$v_i = \frac{s_i}{G_i} \quad \vee \quad s_i = G_i \, v_i \qquad (5)$$

Each deviation is geometrically the orthogonal distance from the corresponding goal hyperplane and the numerical value of this distance is the value of the slack or surplus variable in the goal constraint (Widhelm, 1980). Alternatively, Euclidean distance measures can be used for each slack and surplus variable (Widhelm, 1980; Daellenbach et al., 1983).

$$\left[\sum_{i=1}^{I} (w_i v_i)^p \right]^{\frac{1}{p}} \qquad (6)$$

Euclidean distance (general form of distance metric):

w_i: the weight or penalty given to deviations from goal i

v_i: fractional deviation from target G_i

s_i: slack or surplus variable in the goal i constraints

The MINSUM formulation is as follows:

$$\left.\begin{aligned}
&if\ \mathrm{p} = 1\\
&minimise \sum_{i=1}^{I} (w_i\ v_i)\\
&subject\ to\\
&\sum_{i=1}^{I} Z_i + G_i v_i = G_i\\
&x_i,\ w_i,\ v_i \geq 0
\end{aligned}\right\} \qquad (7)$$

The MINMAX formulation is:

$$\left.\begin{aligned}
&if\ \mathrm{p} \rightarrow \infty\\
&minimise\ v\\
&subject\ to\\
&\sum_{i=1}^{I} Z_i + \left(\frac{G_i}{w_i}\right) v \geq G_i\\
&x_i,\ v \geq 0
\end{aligned}\right\} \qquad (8)$$

Z_i: objective function for goal i
x_i: decision variable for goal i
G_i: target value for goal i
w_i: the weight or penalty given to deviations from goal i
v: single deviation variable
v_i: fractional deviation from target G_i

In this study, the goals making up the model in the GP problem were assessed in different units as incommensurable goals (i.e. units of volume, currency, and utility measurement) and the targets associated with each goal have various different numerical values. The GP model solutions in these two situations can be biased as more importance is given to the goals with higher target values than those with lower ones (Romero, 1991). Therefore, goal constraints for MINMAX and MINSUM formulations in equations (7) and (8) were reformulated in equations (9) and (10).

MINMAX formulation:

$$\left.\begin{array}{c} \textit{minimise } v \\ \textit{subject to} \\ \sum_{i=1}^{I} Z_i + \left(\dfrac{G_i}{w_i}\right) v \geq G_i \\ x_i,\ v \geq 0 \end{array}\right\} \qquad (9)$$

reformulate:

$$\left.\begin{array}{c} \sum_{i=1}^{I} \left(\dfrac{Z_i}{G_i} \times 100\right) + \left(\dfrac{G_i}{w_i \times G_i} \times 100\right) v \geq \dfrac{G_i}{G_i} \times 100 \\ x_i,\ v \geq 0 \end{array}\right\}$$

MINSUM formulation:

$$\left.\begin{array}{c} \textit{if } \mathrm{p} = 1 \\ \textit{minimise} \sum_{i=1}^{I} (w_i\ v_i) \\ \textit{subject to} \\ \sum_{i=1}^{I} Z_i + G_i\ v_i = G_i \\ x_i,\ w_i,\ v_i \geq 0 \end{array}\right\} \qquad (10)$$

reformulate:

$$\left.\begin{array}{c} \sum_{i=1}^{I} \dfrac{Z_i}{G_i} \times 100 + \dfrac{G_i\ v_i}{G_i} \times 100 = \dfrac{G_i}{G_i} \times 100 \\ x_i,\ w_i,\ v_i \geq 0 \end{array}\right\}$$

Z_i: objective function for goal i
x_i: decision variable for goal i
G_i: target value for goal i
w_i: the weight or penalty given to deviations from goal i
v_i: fractional deviation from target G_i

The advantages of GP, especially for MINMAX and MINSUM formulations, are set out, for example, in Field, 1973; Widhelm, 1980; Daellenbach et al., 1983; Glover & Martinson, 1987.

1. Under equal weights one-to-one trade-offs can eliminate the problem of discrepancies between conceptual and algorithmic weights. Furthermore, a clear outline of goal structure implications is appropriate for reviewing and revising decision-making objectives.

2. The MINMAX formulation yields optimal solutions which respond gradually to repeated small changes in the weight structure. In contrast, this minor change in weights in the MINSUM may cause optimal solutions to alter quite suddenly to a nearby extreme point of the feasible region.

3. GP permits post-optimal analysis and trade-offs which are not possible with pre-emptive goal programming formulations.

4. The MINMAX formulation generates the 'best' compromise solution according to the conceptual weights imposed on the objective functions and eliminates the need for the decision maker to scan the set of efficient solutions which, in real-life problems of sizeable dimensions, is an enormous task.

5. Unlike linear programming, no pre-commitment of goal priorities is required. It does not take away from the forestland manager his or her prerogative to choose, as a rational optimisation model would do. It defines the relevant planning alternatives and it leaves the choice under control of the decision maker's subjective judgement.

6. Changing the overall penalty and various goal weights should vary the optimal solutions continuously in a heuristically predictable manner.

These mathematical programming techniques provide problem-solving tools through language while other kinds of programming such as spreadsheets can perform the calculations in order to give insights and are easily usable in decision-making processes. The following section describes features spreadsheets can offer as analytical and support models.

3.2.4. **Spreadsheet Features Performing Analytical and Supported Models**

Spreadsheet programs were originally developed for financial analysis (Wells et al., 1986). They were then adapted to other purposes such as simulation, mathematical programming, forecasting, and statistical programming. Most spreadsheet programs are distinguished by the variety of applications for which they have been designed and utilised (Ronen et al., 1989).

The essential feature of any spreadsheet program is its ability to create and resolve relationships among cells. Most are also user-friendly, being menu-driven, with inbuilt financial, mathematical and statistical functions, graphics, *etc.*

The power of spreadsheets has been further strengthened by boosting analytical capabilities in the programs, with functions for goal seekers and matrix manipulation which helps with problem solving and scenario managers which can save inputs to modes, making 'what if' analysis easier (Aitken, 1992).

Strengthened macro languages add further power by permitting automation of repetitive tasks and by authorising modellers or developers to build stand-alone applications.

Recent spreadsheet development has enhanced modelling capabilities even further to include:

1. the flexibility and ease of use of the dynamic spreadsheet (Aitken, 1993; 1993a);

2. more application in interactive optimisation or tactical and operational optimisation, market segmentation, economic modelling, and labour planning (Jones, 1986; Roy et al., 1989; Winter, 1989; Anthony & Wilson, 1990; Mumford et al., 1991; Sicad, 1993).

Spreadsheet programs are interactive and screen oriented so the memory of a computer can be converted into a large matrix (Sharda, 1988). Bodily (1986) explores spreadsheet-based modelling for optimisation and simulation. He also mentions that spreadsheet has become the central point for bringing greater productivity to the non specialists. Fisher (1986) suggests that spreadsheet-based optimisation with LP can familiarise the user with the optimisation technique.

There are three classes of spreadsheet-based optimisation (Sharda, 1988):

(i) programs which accept a problem formulation from a spreadsheet file (for example, MICROLP, MPS-PC and RAMLP);
(ii) programs which read LP problems from a spreadsheet file and store the optimal solution in a file (for example, JANUS, MAX, MUSAH-86 and XA), and;
(iii) programs incorporated within the spreadsheet, residing in memory within the spreadsheet package. In the last case, the user develops a spreadsheet, presses one or two keys to activate the optimisation algorithm, solves the problem, and returns back to the same point in the spreadsheet. VINO and What's Best fall into this third class as does Solver within Microsoft Excel.

The advantages of using spreadsheet-based models (Bodily, 1986) are:

(i) facilitating greater flexibility in writing reports with graphical outputs;
(ii) handling of sensitivity analysis more easily, and;
(iii) addressing 'what if' questions straightforwardly.

3.3. **An Integrated Regional Planning System for Industrial Forest Plantations**

The next five sections deal with an integrated regional planning system for industrial forest plantations, including monitoring and implementation elements.

3.3.1. **Minimum Economic Size (MES)Spreadsheet-Based Model**

This section covers the theory and implications of minimum economic size. As plantation establishment, management, and harvesting become more mechanised, economics of area size will become more important (Cubbage, 1983). Economics of area size point to the variation in average unit costs which can be realised by varying the size of the operation (Gregersen & Contreras, 1979). The study focuses on model development of minimum economic size for plantation regimes in East Kalimantan.

3.3.1.1. **Theory of MES**

In embarking on a massive plantation establishment programme, there are many policy issues which need to be considered. These include questions such as:

- *where will the plantations be established?*
- *what species will be planted?*
- *what are the ecological and social impacts?*
- *how will the plantations be managed?*
- *what size should the plantations be?*

These important questions are at least partly incorporated within this study. The last question, however, is especially addressed in this section, while others can be seen in Chapters 3.3.1, 3.3.3, and 3.3.4.

References to economics of forest size are rare but studies have include those by Sutton (1968,1969,1973) and Cubbage (1983). In summary, they show that forest size may influence various aspects of forestry such as wood supply availability, management costs, labour considerations and forest protection.

Sutton (1969, 1973) emphasised that forest size and the scale of operations can be important aspects in calculating forest profitability. He also examined the economics of different sizes of New Zealand's State forests. Sutton also drew the following main conclusions:

- the larger the forest size the lower the direct costs per unit area basis, because of spread of overhead and administration costs;
- the larger the forest size the greater the advantages in fire and disease control;
- better management, methods and competition reduce direct costs more than increasing the scale of operation;
- large scale operations can help prevent high costs;

- the larger the forest size the greater the benefits to labour and social aspects;
- the smallest state forest size should not be less than 4000 ha in New Zealand.

These conclusions reflected the state forest cost structures existing at the time.

Cubbage (1983) stated that small forest sizes are likely to have high average costs for forestry treatments. He concluded that most studies of economics of size in forestry indicated that the causes of economies of scale are different from those found in most industrial or manufacturing enterprises. This statement is similar to Clawson's statement saying that there are differences in economic optimum programs between wood growing and wood processing (1976; p.91). Furthermore, better utilisation of mechanisation provides some economies of scale for large areas. Managing such large industrial forestry plantations, however, requires a good forest industrial base, good marketing systems, much capital (at the initial stage), well-trained field operators and field workers, skilled project management, and general government support in the form of financial (e.g. loans, grants, guarantees, and the building of infrastructures) and technical support (Palin, 1980; Anonymous, 1986; Anonymous, 1989a; Chapman & Allan, 1978). The optimal solution in a standard forest management problem is influenced by the preferences of the decision-maker, market conditions, and public negotiation (Gong, 1994).

Long-term industrial forestry plantation development plans are urgently needed in this regard. For example, market planning would influence minimum area of planting sizes in order to ensure minimum marketable volumes, while research planning would dictate the production of high quality outputs from plantations in terms of end-values and competitiveness. Furthermore, the Ministry of Forestry could, of course, have a role to play, but what is more important is a stable investment environment and access to quality research and development providers.

The New Zealand study and the United States studies indicate that mechanisation is one of the important considerations because it relates directly to fixed costs in forest management. It is assumed that labour cost is not cheap but in most developing countries, including Indonesia, sufficient and cheap labour for clearing and planting can be obtained. Therefore, such studies, while inherently relevant to Indonesia's context, need to be modified.

Minimum plantation sizes are affected by several factors such as (Pöyry, 1987):

- the minimum volume for forest industry processing;
- economies of scale in forest management;
- the minimum volume requirement for market penetration efficiency.

It should be realised that industrial forestry development is not as simple as growing trees. It can have many negative and positive impacts on social, economic, and environmental factors. For example, plantations cannot be separated from downstream effects (e.g., water resources) and from the local cultural life surrounding those plantations. Consequently, a long-term perspective is essential in order to explain the whole impact of the industrial plantation development on socio-economic and environmental factors.

Theoretically, there are four equal considerations for an industrial plantation to obtain a sizeable and perpetuating influence on global long-term wood supply (Evans, 1982; Sedjo, 1983; Anonymous, 1989a):

1. fundamental economics have to be favourable;
2. land availability for industrial plantation has to be substantial;
3. existing and new wood processing industries can be developed, and;
4. domestic and export markets can potentially exist.

Firstly, for the economics of an industrial forest plantation to be favourable, a minimum size must be considered in the context of the following two main factors.

1.1. Forest plantations can be for either wood production (sawlog, plylog or pulplog) or for non wood production (environmental purposes) or for some combination of the two. For example, Evans (1982) gives an approximate minimum feasible size for a new sawlog plantation in tropical countries of about 1000 ha in order to supply an existing integrated sawmilling operation. It is assumed that MAI for sawlog is 15 $m^3 ha^{-1} an^{-1}$, therefore, the total sawlog volume is 15 000 m^3 annually. Groome Pöyry (1994) reported that minimum annual log input for sawmill in Laos is 20 000 m^3. Those two findings are mainly based for domestic markets whereas Edgar, et al (1992) assume that an international competitive sawmill in New Zealand, its log input capacity is 200 000 $m^3 ha^{-1} an^{-1}$.

1.2. Social responsibilities: Sumitro & Sudiono (1978) conclude that forestry plantations could be a source of employment in rural areas. They provide figures to show that plantations require 70-400 man-days per hectare at the initial establishment stage and 9-13 man-days per hectare for management of established plantations. Local or regional labour requirement and availability will be a significant factor in establishing and maintaining industrial plantations. In addition, the man-days per hectare for any given plantation regimes would depend on the level of tending for significant opportunities exist for more intensive management of tropical hardwood plantations for solid wood end-users.

Secondly, industrial forestry plantations need substantial land areas. Land availability and land capability (or quality) may not only vary from one tropical country to another country (Evans, 1982; Anonymous, 1989a), but also to non tropical countries and within each countries. This land availability has to be addressed more fully in East Kalimantan as a case study region through current legal status of forestland designation (forestland-use by consensus or TGHK). Furthermore, it should be noted that:

- plantations are usually in regular shapes with clear boundaries (only where geography allows);
- the more fertile the areas, the more productive are the plantations;
- the flatter the areas and the closer the areas to the processing plants, the less expensive logging operations will be;

- the more compact the shape of the areas, the less expensive management operations will be.

Land availability has some direct controls depending on land use aspects and land tenure. These two direct controls are still not easy problems in most tropical countries (Adeyoyu, 1976; Evans, 1982; Anonymous, 1989a). Shifting cultivation is a current example (Anonymous, 1987).

Most forestlands in tropical countries belong to the governments which regulate their use (Anonymous, 1987a) but it should be noted that those forestlands can be categorised under, for example, customary ownership or private ownership (Anonymous, 1967). As an aside, laws relating to tenure could also be an issue in temperate countries, e.g. Maori land in New Zealand.

The degraded grasslands (where industrial plantations are still technically and silviculturally possible) and parts of logged-over forests are suggested locations for large industrial plantations (Anonymous, 1987a).

Thirdly, a minimum size of industrial plantation can be calculated by investigating forest product processing options. But this simple investigation contains inherent difficulties. These were highlighted by Clawson (1975; p. 91):

> *"Since a forest industry is, by definition, part of a firm that has wood processing facilities, there is the possibility that the economically optimum program for timber growing will not be the same as the economically optimum program for wood processing; if so, which dominates, or is it the combined program which is dominant?"*

If log exports or log imports are a possibility, there is scope for optimising both. Furthermore, the minimum capacity of, for example, a sawmill, to be internationally competitive is not well known. However, small and large sawmills with 200 000 m^3 and 400 000 m^3 log intake annually could be used as a guide (Edgar, et al (1992). It should be understood that the minimum industrial plantation size for non pulp log or pulp log production and export orientation, should be based on international timber grading. In addition, it depends on species sawn and what kind of products are to be produced.

Fourthly, domestic and export markets will alter not only the minimum number of industrial plantations needed to be established to ensure a minimum marketable volume, but they will also influence (Pöyry, 1987):

- choice of area for domestic and export market opportunities;
- integration of plantation with processing ownership;
- choice of species.

For industrial plantation sawntimber production, an ideal tree would be a fast growing species with the ability to grow to a large size, one which has good form, is easy to prune, has material strength, dimensional stability, good seasoning, and capabilities for preservation working and finishing characteristics (Evans, 1982). The species choice can be obtained from both indigenous species and exotics. Moreover, different species can cause differences in the time of planting, different planting orientations, planting pattern and initial spacing. Initial spacing[1] influences costs of establishing plantations (Price, 1989; Evans, 1982). Price and Evans both conclude that if the spacing is close, it will induce higher planting costs. For example, planting costs for a given species planted at 3 x 3 m is cheaper than at 2 x 2 m spacing. Price (1989) adds that one important factor influencing optimal spacing is presence or absence of a well-developed market for quality timber. The species would also be recognised in the marketplace with an established demand in high-value uses which is obvious. What is important are the consequent downstream effects on further tending, harvesting, log quality and utilisation.

An additional restricted factor when considering spacing is survival rate. If survival is 95 per cent or more, then blanking will not be required, and lower initial spacings may be justified on the basis of lower initial costs. However, if survival rates are not so high, then higher initial stockings may be needed to help compensate expected losses. Blanking is expensive, and tends to result in trees which will need to be culled anyway because they are getting a later start than their competitors.

The next section explains the development of a minimum economic size spreadsheet-based model for this study.

3.3.1.2. Development of the Minimum Economic Size Spreadsheet-Based Model

- **General Description**

The MES model is the spreadsheet format which uses plantation costs and revenues and internal and external economic considerations to generate the minimum economic size for related plantation regimes.

Cost schedules are divided into five main components: nursery costs; establishment and silviculture costs; fire and disease costs; roading construction and maintenance costs; and administration, building, and contingency costs. These costs include semi-variable costs, namely a step function which takes on discrete values over some range of the independent variable. In other words, these cost structures remain fixed over a range of outputs and then suddenly increase substantially, and again remain fixed for a while before taking another leap (Kaish, 1976).

Three sub-models can be recognised within the MES model (Figure 3.2): (i) costs sub-model; (ii) revenue sub-model, and (ii) cashflow sub-model.

[1] One of the main determinant of initial spacing is genetic quality and selection ratio for final crop stocking. It can only be lower if the assurance of sufficient good quality final crop stems is available.

4.c. Harvest roads are up-graded establishment roads in the year preceding thinning and harvesting of the areas. These roads may reduce the total roading cost and maintenance. Road maintenance is given for access roads and establishment roads every six years and one year respectively. Appendix 3.1 shows the cost structure and Appendix 3.2.D shows the roading construction and maintenance costs schedule.

5. Administration, building and contingency costs.

5.a. Housing, office, workshop, and equipment costs are weighted differently for every plantation size. These constructions are indicated in the first year and are excluded from the nursery construction costs. Appendix 3.1 shows the cost structure and Appendix 3.2.E shows the administration and general costs schedule.

5.b. Housing maintenance is carried out every five years whereas office (and workshop) maintenance is given for every 10 years.

5.c. Planning costs can be categorised into three types:

- *RKT* (*Rencana Karya Tahunan* or Yearly Working Plan);
- *RKL* (*Rencana Karya Lima Tahun* or Five-Year Working Plan).
- *RKPHTI* (*Rencana Karya Pengusahaan Hutan Indonesia* or Industrial Forest Plantation Long-Term Planning).

5.d. These costs per hectare vary with the size of the plantation (step-wise as per Kaish (1976)).

Appendices 3.2.F, 3.2.G, and 3.2.H show the schedules for thinnings and harvesting, revenue, and total costs and revenues. Appendices 3.3.A, B, C, D, and E show the weighted cost details for nursery, establishment, roading, fire and disease, administration and overhead costs.

- **Revenue sub-model**

1. Thinning and harvesting schedules.
2. Revenue schedules.

- **Cash flow sub-model**

1. Cash flow.
2. Financial analysis.

Output from this MES model can be attached to the Forestland Allocation Model. Some assumptions are needed in order to develop the MES model and calculate the minimum economic area required for sawlog plantations. Assumptions dealing with the MES model development are as follows.

1. Forest management in this model refers to industrial forest plantations using clear-felling for pulp and non pulp log outputs.

2. Existing wood processing annual capacities and market demands are likely to be changing in the next 30-40 years (1995 - 2035).

3. Development of plantation regimes can be carried out by either local private, state-owned, or multinationals forest enterprises.

4. Plantation activities include land clearing and preparation, silvicultural activities (such as establishment of nurseries, planting, weeding, fertilising) and forest management elements (such as pruning, thinning, and fire and disease control).

5. Planting might take place in logged natural forest areas and on unproductive forest areas with various site types. It is assumed that different grades of soil produce different returns.

6. Initial spacing of planted trees can be either 2.0 x 2.0 m (2 500 per ha) or 2.0 x 3.0 m (1 667 per ha) or 3.0 x 3.0 m (1 111 per ha) depending upon the chosen species. It is assumed also that very close planting is expensive and very wide planting need larger areas; therefore, planting espacement are determined by the chosen species, the area, the objective of crop management and harvesting variables (Mash, 1978). Larger trees are desirable to improve recovery during end-use conversion. These are called plantation clearwood regimes for radiata pine (Lavery, 1986).

7. Primary species for this study can be chosen on the basis of analysis in the NMFP report (National Masterplan for Forest Plantations). There are three possible species for each plantation regime.

8. Plantation areas relate to the annual log intake demands of processing plants, and range from 5 000 ha to 200 000 ha.

9. Administrative activities, construction, e.g., buildings and road or plantation access tracks, equipment and staffing are also included as an integral part of plantation development.

10. The purpose of analysing the minimum economic size plantation is to lower the long-term costs per unit, even though the most important requirement is the maximisation of net revenue on a sustainable basis. The prices and costs employed in the analyses are obtained from various sources such as reports, publications, personal communications, and hypothetical data.

11. Three assumptions are used for sensitivity analysis.

    11.1. Three per cent increase in all costs. The implementation of industrial forestry plantation can have some significant risks on account of economic and social variations. Those variations cannot be ignored in Indonesia's circumstances. Therefore, a 3 per cent increase in all costs is chosen in order to allow for those variations.

    11.2. Non pulp log prices increase at 0.3 per cent annually until specified clearfell ages while all corresponding pulpwood prices increase at 0.1 per cent annually. Future various log prices in Indonesia are unlikely to be constant. All prices increase in real terms. Real terms mean evaluation that excludes the changing value of money, inflation and deflation (Gregersen & Contreas, 1979).

    11.3. Combination of assumption (11.1) and assumption (11.2).

• Model Structure

The general structure of the MES model proposed here is to calculate NPV and IRR subject to cashflow considerations. Figure 3.2 shows the model structure and the link between outputs from this model and the Forestland Allocation model.

Financial analysis is carried out from costs and revenues. The basic objective of this financial analysis is to compare the relationship between expected costs and revenues for any given plantation regime. Some formulae for this financial analysis are presented in Fraser, 1986; Levack & McGregor, 1986:

$$Total\,Cost\,per\,ha = \frac{Total\,Cost\ (\$)}{Total\,Area\ (ha)} \qquad (11)$$

Total cost per ha equals to total costs divided by total area (equation (11)), where total costs equals to total fixed costs (e.g. administration, housing, office, workshop and storage and warehouse, and planning costs) plus total variable costs (e.g. nursery (for seedlings), establishment (area survey, direct supervision, land preparation, planting, beating-up, weeding, fertilising, thinning), fire and disease (operating costs), and harvesting (operating costs) and total semivariable costs (e.g. nursery, establishment, roading, fire and disease, and administration (machine investment and replacement).

Equation (12) finds the present value now (V_0) of future values, which are costs and revenues (i.e. money received from selling thinnings and final harvests) in the given financial year t. Equation (13) separates equation (12) into total revenues and total costs discounted annually for t years at the internal rate of return d.

$$V_o = V_t \left[\frac{1}{(1+i)^t} \right] \qquad NPV = \sum_{t=0}^{n} \frac{(R_t - C_t)}{(1+i)^t} \tag{12}$$

$$\sum_{t=0}^{n} \frac{R_t}{(1+d)^t} = \sum_{t=0}^{n} \frac{C_t}{(1+d)^t} \tag{13}$$

V_o: present value of a sum
V_t: future value in year t of a sum
R_t: Gross revenues in year t
C_t: Gross costs in year t
i: the relevant alternative rate of return
d: internal rate of return (IRR)
t: time interval; $t = 0, 1, \ldots, n$

- **Implementation**

The MES model was developed using Quattro Pro® version 5.0 (Borland, 1994). This spreadsheet software allows setting up the problem in distinct parts and utilising macros for multiple model runs. Model outputs are located in Chapter 4 where Tables 4.2, 4.3, 4.4, and 4.5 show the species options, and financial comparisons (i.e. total cost per hectare, NPV per ha, IRR).

The next sequence of sections deals with the proposed regional industrial forest plantation planning structure, including monitoring and evaluation elements.

3.3.2. Multi-Objective Decision Making (MODM) Model

Coordinating activities in forestland-use and forest planning should be an integral part of overall land-use activity, confirming full approval by decision makers, local institution and decision receivers for permanent forestland. ITTO (1990) proposes integrated land-use planning including two related activities:

1. for strengthening policy initiatives comprising the forest sector;
2. that duplicate development of a legal framework related to land-use and permanent forest estates.

Those two related activities could be undertaken by means of:

(i) comprehensive studies to determine:

- the demand for non forest products (e.g. domestic and export) and forest products (e.g. environmental protection);
- the apacity of existing forest estate to provide goods and service;
- the location and the extent of the planted forests that will be needed to supplement existing forest;
- local community demand for economic, spiritual, and cultural values.

(ii) laws and regulations enactment at local, regional, and national levels.

Forest management in Indonesia acknowledges that producing forest products is only one of the multiple roles of forests. In addition, to preserving biological diversity and contributing to climate stability, forests also protect water resources and soil stability. Other important roles are to improve the welfare of local communities. Therefore, those forests are required to be managed in the context of sustainability of all these aspects. According to the Basic Forestry Act (1967), forest utilisation should be based on the principle of sustained yield for multi-purpose uses. This utilisation plan encompasses soil and water conservation, managing forest product resources, arrangement of a source of living for local communities, preservation of fauna and flora, supporting transmigration programs, agricultural uses, and other public services.

Based on the above conditions, the forestland use plan was formulated for Indonesia's 144 million hectares of forestlands by function as follows:

Table 3.2. **Forestland Categories based on the TGHK**

Function	*Area* (1 000 ha)	*Percentage* (%)
• Protection forest	30 319	21
• Park & conservation forest	18 752	13
• Limited production forest	30 526	21
• Production forest	33 867	24
• Conversion forest	30 517	21
Total forestland:	143 981	100

Cited from MoF (1989).

By the year 2000, Indonesia's current natural forests may not be adequate to supply the increasing demand both from domestic demand and from the processing industries (Mangundikoro, 1984; 1985; Spears, 1984). Therefore, the primary role of industrial forest plantations as a supplement to natural forests will be very crucial for future wood supply and conservation purposes. The GoI (Government of Indonesia) has embarked and has been encouraging a large-scale industrial forest plantation development since 1985 with the following primary objectives (National Masterplan for Forest Plantations (NMFP), 1993):

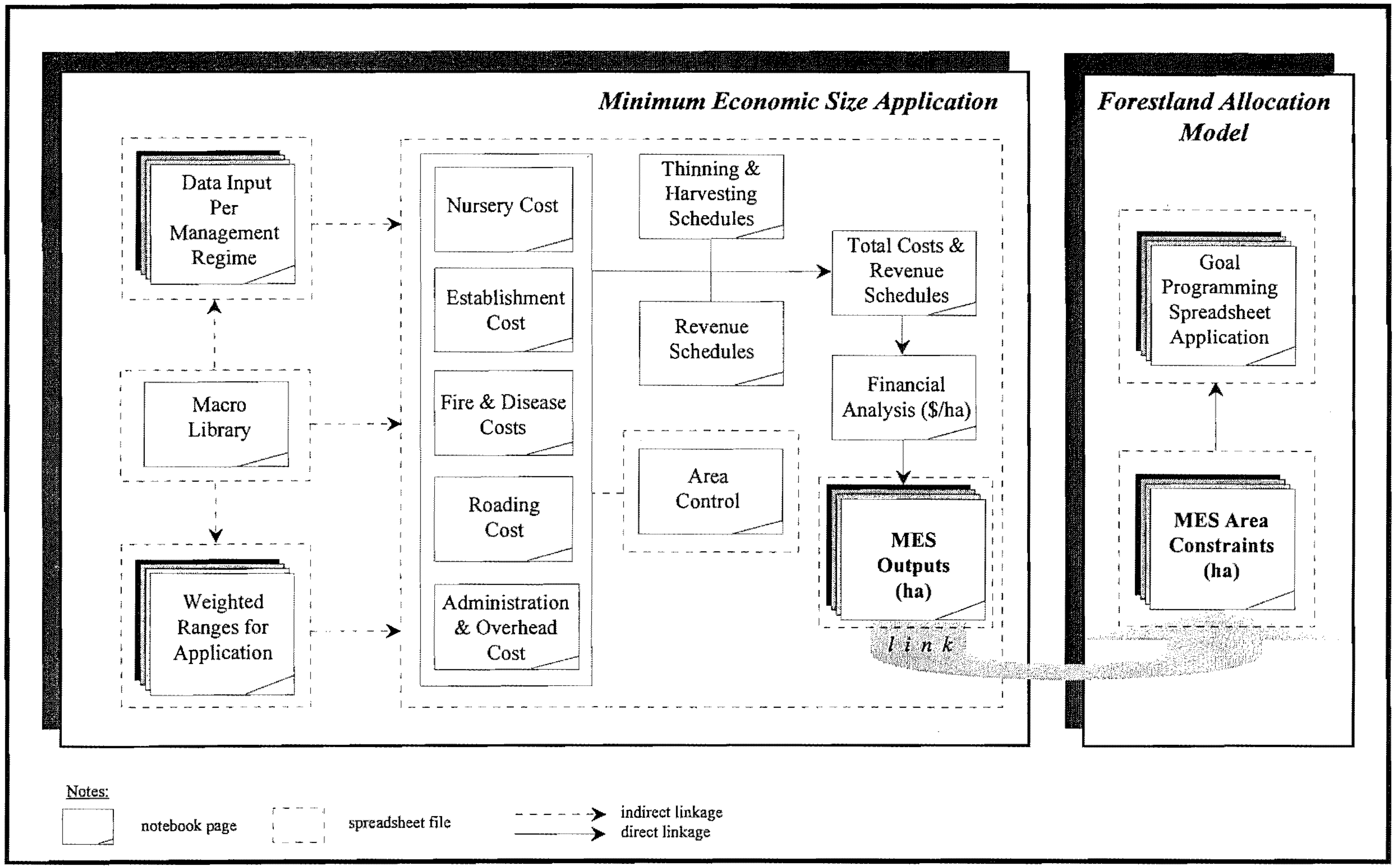

Figure 3.2. Linkage between The Minimum Economic Size Application (MES) and Forestland Allocation Models

1. ensuring wood supply to processing industries;
2. rehabilitating degraded lands;
3. protecting watershed for soil erosion control;
4. biodiversity and environmental conservation;
5. regional development and employment of local communities, and;
6. poverty alleviation both through employment and direct benefits of planting.

National Masterplan for Forest Plantations report (NMFP, 1993) predicts a requirement for 6.67 million hectares of industrial forest plantations in order to meet the existing and future demand by the year 2030. Further forestland database updated in terms of its national and regional or provincial availability under legal forestland tenure considerations - such as customary rights (or traditional law), Agrarian law, and forestland-use by consensus (TGHK)- are still being carried out. The West Kalimantan region was selected as the first phase project in the NMFP report (MoF, 1995) which will be an important factor in determining the forestland allocation for industrial forest plantation development.

The NMFP report deals with 5 major provinces:

(i) Irian Jaya (2.17 million ha or approximately 32 per cent of the total 6.67 million ha proposed plantations);
(ii) East Kalimantan (2.13 million ha or nearly 32 per cent);
(iii) Central Kalimantan (0.86 million ha or approximately 13 per cent);
(iv) South Sumatera (0.38 million ha or approximately 5 per cent), and;
(v) South Kalimantan (0.37 million ha or nearly 5 per cent).

East Kalimantan is selected as the case study region.

With over 75 per cent of the surface area of East Kalimantan Province in forestland, the province has long realised the importance of planning for forestland allocation among various management regimes. The latest assessment (NMFP, 1993) indicates that about 6.2 million ha could be categorised into 13 possible plantation management regimes based on land status, land suitability, population density and standard development area. About 2.13 million ha of suitable forestland has already been assigned to industrial forest plantations over the next 20-30 years (*ibid*).

Conceptually, land has a geographical location and possesses variable capacity to allow different management regimes. Therefore, allocating these forestlands to various management regimes is complicated. In terms of a forestland capability and suitability approach, a forest planner wants to know how to put these criteria to use in an effective way. In other words, answers have been sought to assess these criteria in the context of given political, economic, and environmental needs including social issues.

Even though this approach is straightforward and easy to understand, there have been practical limitations to its implementability. Firstly, those needs have to be known exactly in order to have a quantifiable value system so that comparisons may be made between:

- different management regimes on the same forestland;
- different forestlands for the same management regime.

A more satisfactory and objective method of trade-off must be developed in order to determine what to do with data which are already available and what if any additional data should be collected in order to make good forestland allocation decisions.

3.3.2.1. **Problem Statement**

The forestland allocation model described here has been devised to produce a research tool that can optimise and focus on the given capabilities of forestland in the East Kalimantan region.

This forestland allocation model has been developed in order to improve the quality of decision-making in regional industrial forest plantation development planning by:

1. providing a methodology for improved interaction between transparency of the sub-parts of the whole decision making process (see Figures 3.1 and 3.2) via GP approaches, namely, MINMAX and MINSUM formulations. The interactive and transparent aspects are between the decision makers and the stakeholders (or public). The methodology should increase their roles and level of understanding by providing a common knowledge base and transparent value sets;

2. contributing pre-empirical validation and testing of these two GP approaches via a wide range of solutions, and;

3. demonstrating that even though the GP disadvantage - that it is more likely to produce too many solutions from which to choose as Hannan (1985) mentioned - these two GP approaches will still be usable for their solutions' accuracy and applicability to real-world problems, simplicity of use and simplicity of computer programs to execute the algorithm.

Producing a development plan for a regional industrial forest plantation is a complex task because there are many real issues, all inter-related, inter-dependent and often conflicting. Some form of compromise is usually required to resolve the real issues in generating a development plan.

This interactive methodology comprises utility value and allows involved groups with their competing and conflicting values to contribute to regulating the forestland allocation. Furthermore, it constructs a compromise form of decision making for regional industrial forest plantations.

The recent development and involvement of large-scale enterprises from the private sector in industrial forest plantation development has increased plantings, while their silviculture also seems to be of a high standard (NMFP, 1993). Furthermore, reforestation run mostly by the government, has been disappointing and the re-greening programme involving local communities does not appear to have significantly boosted forestlands, though it is difficult to be certain of the actual impact (*ibid*).

Business on a big scale seems to be the best way to achieve successful forestlands by tree planting, but this prognosis is far from complete (NMFP, 1993). To varying degrees all these schemes have generated conflict: for example, the rights of local communities to use forestland and to mitigate environmental impacts. This is inevitable with any large-scale development.

In summary the major issues, though not necessarily in sequence, are:

1. *why plantations?*
2. *what exactly are they to produce?*
3. *how to ensure plantations are successful?* (and criteria for successful plantations)
4. *how to distribute forestland among possible alternatives? (or where will these plantations be located?)*
5. *how to get reliable data and an updating system for them?*
6. *how to plan these plantations efficiently?*

As indicated earlier, a total area of about 2.13 million ha of East Kalimantan region was chosen for the case study. A hypothetical map of the region with existing forestland use and proposed locations is shown in Figure 3.3. Because of the large area not yet covered by the NMFP (Tyrie[2], *pers. comm*), a hypothetical but realistic example has been set up.

Appendix 3.4 shows the spatial location and distribution of various crop types throughout the 2.13 million ha. In this case study, a crop type is taken to represent a function of location, management regimes and species. The decisions to be made involve the forestland allocation for each proposed crop type among five spatial locations. The following crop type criteria are considered: (i) location where different locations have different locational productivity; (ii) management regime; and (iii) species. The second and third criteria are provided from the NMFP report (NMFP, 1993). Table 3.3 shows those criteria and management regime options. Appendix 3.4 lists the hypothetical location distribution whereas Appendix 3.6 presents coefficients for individual crop type.

This case study region is dominated by systems of high, rugged, strongly folded and faulted mountains, low mountains, and rugged hills to undulating plains (Bremen et al., 1990). The altitude ranges between 50 and 1500 metres. Furthermore, in the upland areas, strongly weathered, very deep to extremely deep, moderately well to well drained soils are dominant (Bremen et al., 1990). Figure 3.3 shows this geology and the topography of the region.

Forestland is allocated to a given crop type or management regime with a view to procuring certain desirable outputs or limiting certain undesirable effects. These considerations are due to forestland capability, altitude and topography. In this case, location 2 is the only location that covers all four management regime options (WPPC, HTIT, IGT and PP) whereas

[1] Graham Tyre is the project leader of the National Masterplan for Forest Plantations in Indonesia (1994-1995).

this is a single management regime, WPPC, for location 5. The latter location is located further away from processing centres and lowlands, and so sound watershed protection and commercial management policies are applied. Location 1 consists of WPPC, IGT and PP, with WPPC and IGT for location 3 and WPPC and HTIT for location 4.

Table 3.3. **Crop Type Criteria in Forestland Model**

Criteria	① location	② management regime	③ species
• spatial boundaries	5 locations \a 1. Location 1 2. Location 2 3. Location 3 4. Location 4 5. Location 5		
• selected options		4 management regimes:	3 species for each management regime
		1. WPPC \b	1.1. Albizzia falcataria 1.2. Calliandra calothyrsus 1.3. Dalbergia latifolia
		2. HTIT \c	2.1. Albizzia falcataria 2.2. Eucalyptus deglupta 2.3. Gmelia arborea
		3. IGT \d	3.1. Eucalyptus deglupta 3.2. Eucalyptus urophylla 3.3. Gmelia arborea
		4. PP \e	4.1. Acacia mangium 4.2. Eucalyptus deglupta 4.3. Eucalyptus urophylla

Notes:
\a see Figure 3.3 Appendices 3.4 and 3.6 for details.
\b Watershed Protection Part Commercial.
\c Industrial Forest Plantation-Transmigration.
\d Industrial Grade Timber.
\e Pulp Plantation.

Code for crop types are shown by Appendix 3.6 where their general rule of codes is as follows:

- L_k stands for location k, where $k = 1, 2, 3, 4$, and 5
- M_l stands for management regime l, where $l = 1, 2, 3$, and 4
- S_m stands for species m, where $m = 1, 2$, and 3

Three promising species for each management regime were selected (Table 3.3). A set of alternative forestland allocation is then generated which covers all feasible combinations of all management regimes, species and location. After initiating some obvious geographical and spatial constraints, the number of variables was reduced to thirty six from sixty (4x3x5) and evaluated with respect to six objectives described in the next section. Appendix 3.6 lists coefficients for these variables.

Finally, this forestland model's outputs are then used in an integrated fashion in linking optimisation and simulation models. Figure 3.4 shows the linkages among the Forestland Allocation Model, Optimisation-Simulation and GIS at the regional level.

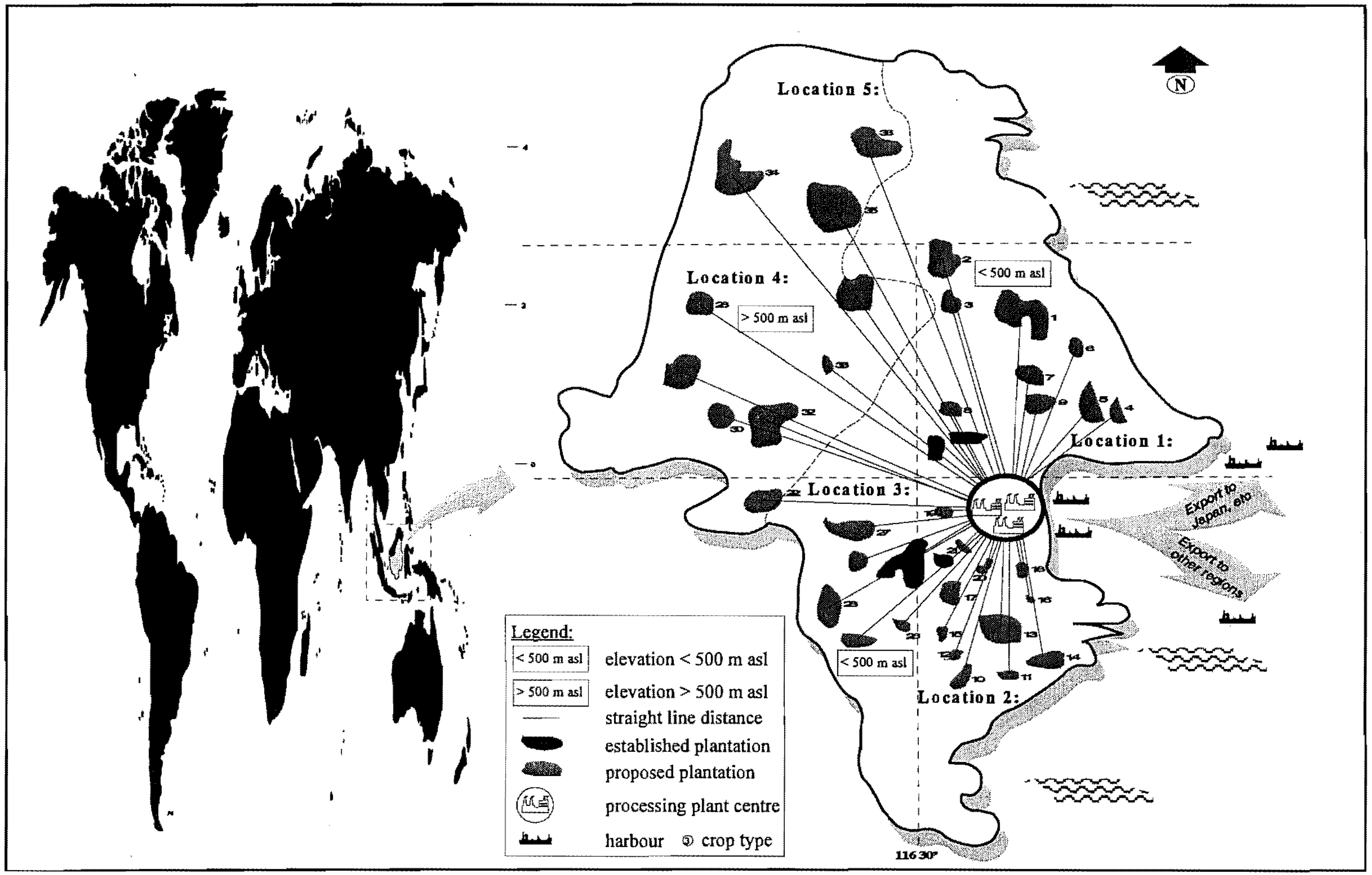

Figure 3.3. Hypothetical Proposed Industrial Forest Plantation Development for East Kalimantan

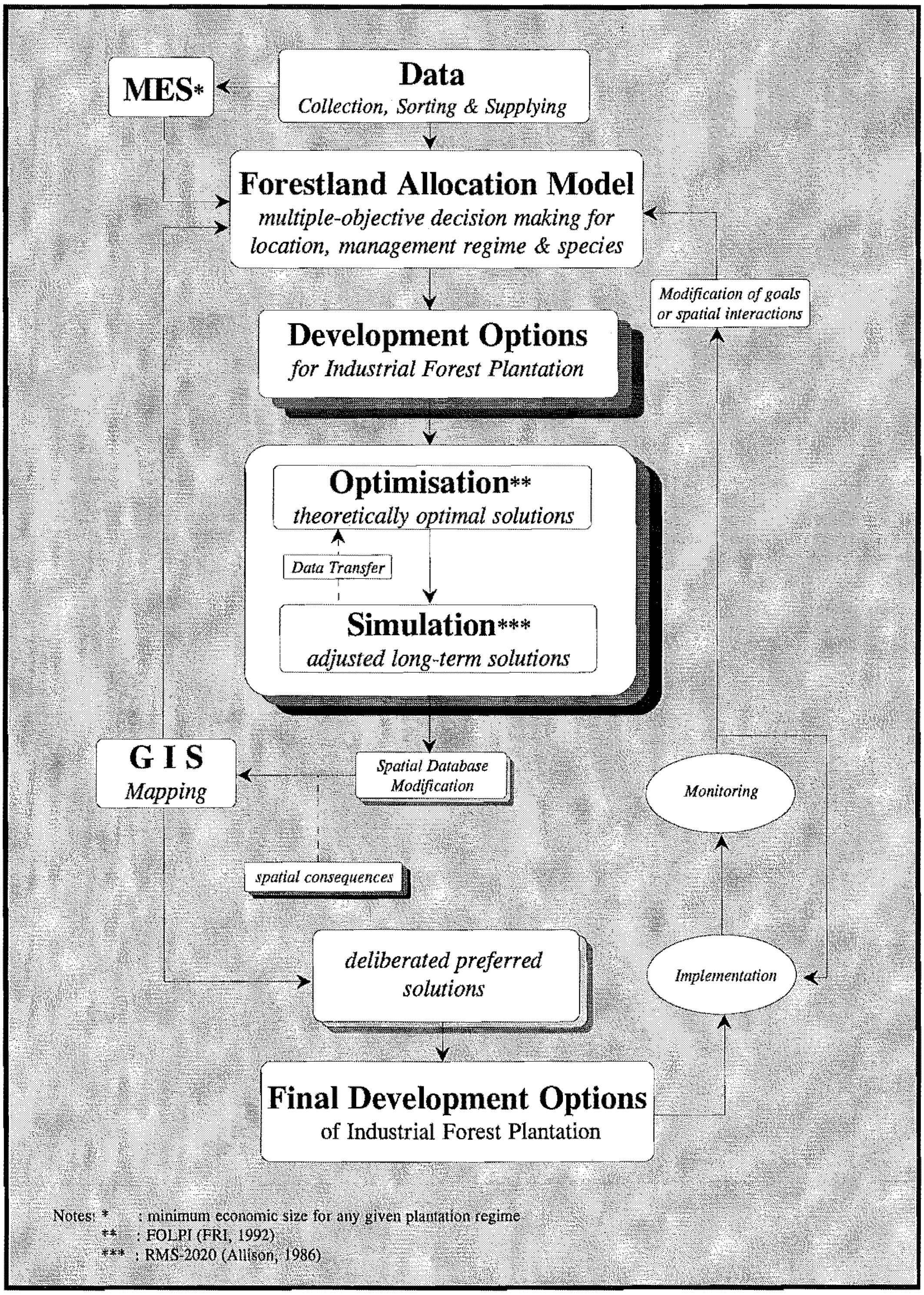

Figure 3.4. Linkage between Forestland Allocation Model, Optimisation-Simulation and the GIS at the Regional Level

3.3.2.2. **The Basic Model Formulation**

There are several important assumptions underlying the model, examples of which are as follows.

1. Forestland capability shows up only in the form of productivity per hectare. Forestland capability is assumed to be the same for different forestlands for the same management regimes and species. For example, in *location 1* where *management regime 1 species 1, 2* and *3* ($L_1M_1S_1$, $L_1M_1S_2$ and $L_1M_1S_3$) have their own yields per hectare are exactly the same for *location 4* where $L_4M_1S_1$, $L_4M_1S_2$ and $L_4M_1S_3$ are also appropriate.

2. A piece of forestland can be allocated to one crop type only, and not to several crop types at the same time and space. Compatibility of various crop types is considered.

3. Minimum economic area criteria can be utilised and attached as the lower bounds for area constraints. MES can be attached before or after the model is run, depending on the model outputs. Base case MES model outputs were applied in this way to the LP and GP models.

In this study six possible objectives are considered to illustrate a more satisfactory way of analysing the forestland allocation problem. The first two objectives, maximisation of non pulp and pulp log productions. These two basic objectives were included in the model formulation in order to derive two different major log types in the processing side. The third and fourth objectives were maximisation of watershed management through soil protection and maximisation of subsistence of local community. The next objective was maximisation of revenue for organisation from the forestland. The last objective was maximisation of the readiness or arrangement of the plantation options. The two latter objectives were an attempt to quantify the financial and technical issues which were so important to the decision makers as stated in Whyte (1990) referred to earlier in section 3.1.

These selected objectives are:

- Maximise total non pulp production (*objective 1*)
- Maximise total pulp log production (*objective 2*)
- Maximise soil protection (*objective 3*)
- Maximise subsistence of local community (*objective 4*)
- Maximise revenue for organisation from the forestland (*objective 5*)
- Maximise the readiness or arrangement of the plantation options (*objective 6*)

Those six individual objectives can be written as:

$$\left.\begin{aligned}
\text{Max: } Z_1 &= \sum_{k=1}^{5}\sum_{l=1}^{4}\sum_{m=1}^{3} P_{klm}\, X_{klm}\\
\text{Max: } Z_2 &= \sum_{k=1}^{5}\sum_{l=1}^{4}\sum_{m=1}^{3} Q_{klm}\, X_{klm}\\
\text{Max: } Z_3 &= \sum_{k=1}^{5}\sum_{l=1}^{4}\sum_{m=1}^{3} R_{klm}\, X_{klm}\\
\text{Max: } Z_4 &= \sum_{k=1}^{5}\sum_{l=1}^{4}\sum_{m=1}^{3} S_{klm}\, X_{klm}\\
\text{Max: } Z_5 &= \sum_{k=1}^{5}\sum_{l=1}^{4}\sum_{m=1}^{3} T_{klm}\, X_{klm}\\
\text{Max: } Z_6 &= \sum_{k=1}^{5}\sum_{l=1}^{4}\sum_{m=1}^{3} U_{klm}\, X_{klm}
\end{aligned}\right\} \qquad \textbf{(14)}$$

$$\text{Min } \sum_{i=1}^{6} w_i v_i \quad \text{MINSUM formulation} \qquad \textbf{(15)}$$

$$\text{Min } v \quad \text{MINMAX formulation} \qquad \textbf{(16)}$$

Subject to:

1. Area constraints for every location, management regime and species:

$$X_{klm} \le A_{klm} \qquad \textbf{(17)}$$

$$\sum_{l=1}^{4}\sum_{m=1}^{3} X_{lm} \le A_{lm}\ ; \quad k = 1,2,3,4,5. \qquad \textbf{(18)}$$

2. Non pulp log and pulp log production per location:

$$\left.\begin{aligned}
&\sum_{l=1}^{4}\sum_{m=1}^{3} P_{lm}\, X_{lm} \ge E^{o}_{lm}; \quad k = 1,2,3,4,5.\\
&\sum_{l=1}^{4}\sum_{m=1}^{3} P_{lm}\, X_{lm} \le F^{o}_{lm}; \quad k = 1,2,3,4,5.
\end{aligned}\right\} \quad \textbf{(19)}$$

$$\left.\begin{aligned}
&\sum_{l=1}^{4}\sum_{m=1}^{3} P_{lm}\, X_{lm} \ge D^{o}_{lm}; \quad k = 1,2,3,4,5.\\
&\sum_{l=1}^{4}\sum_{m=1}^{3} P_{lm}\, X_{lm} \le C^{o}_{lm}; \quad k = 1,2,3,4,5.
\end{aligned}\right\} \quad \textbf{(20)}$$

3. Goal constraints for MINMAX formulation:

$$\left.\begin{aligned}
&\sum_{k=1}^{5}\sum_{l=1}^{4}\sum_{m=1}^{3} \left(\frac{P_{klm}\, X_{klm}}{G_1} \times 100\right) + \left(\frac{100}{w_1}\right) v \ge 100\\
&\sum_{k=1}^{5}\sum_{l=1}^{4}\sum_{m=1}^{3} \left(\frac{Q_{klm}\, X_{klm}}{G_2} \times 100\right) + \left(\frac{100}{w_2}\right) v \ge 100\\
&\sum_{k=1}^{5}\sum_{l=1}^{4}\sum_{m=1}^{3} \left(\frac{R_{klm}\, X_{klm}}{G_3} \times 100\right) + \left(\frac{100}{w_3}\right) v \ge 100\\
&\sum_{k=1}^{5}\sum_{l=1}^{4}\sum_{m=1}^{3} \left(\frac{S_{klm}\, X_{klm}}{G_4} \times 100\right) + \left(\frac{100}{w_4}\right) v \ge 100\\
&\sum_{k=1}^{5}\sum_{l=1}^{4}\sum_{m=1}^{3} \left(\frac{T_{klm}\, X_{klm}}{G_5} \times 100\right) + \left(\frac{100}{w_5}\right) v \ge 100\\
&\sum_{k=1}^{5}\sum_{l=1}^{4}\sum_{m=1}^{3} \left(\frac{U_{klm}\, X_{klm}}{G_6} \times 100\right) + \left(\frac{100}{w_6}\right) v \ge 100
\end{aligned}\right\} \quad \textbf{(21)}$$

4. Goal constraints for MINSUM formulation:

$$\left.\begin{aligned}
\sum_{i=1}^{I} \frac{P_i}{G_1} \times 100 + 100\, v_1 = 100 \\
\sum_{i=1}^{I} \frac{Q_i}{G_2} \times 100 + 100\, v_2 = 100 \\
\sum_{i=1}^{I} \frac{R_i}{G_3} \times 100 + 100\, v_3 = 100 \\
\sum_{i=1}^{I} \frac{S_i}{G_4} \times 100 + 100\, v_4 = 100 \\
\sum_{i=1}^{I} \frac{T_i}{G_5} \times 100 + 100\, v_5 = 100 \\
\sum_{i=1}^{I} \frac{U_i}{G_6} \times 100 + 100\, v_6 = 100
\end{aligned}\right\} \qquad \textbf{(22)}$$

5. Non negativity:

$$X_{klm},\ w_i,\ v,\ v_i \geq 0 \qquad \textbf{(23)}$$

Z_1:	maximise non pulp log production
Z_2:	maximise pulp production
Z_3:	maximise soil stability
Z_4:	maximise subsistence for local community
Z_5:,	maximise revenue for the organisation
Z_6:	maximise readiness of the plantation options
X_{klm}:	area (hectare) assigned to location k management regime l and species m
P_{klm}:	expected yield for non pulp production of location k management regime l and species m
Q_{klm}:	expected yield for pulp production of location k management regime l and species m
R_{klm}:	utility scale for soil erosion stability of location k management regime l and species m
S_{klm}:	utility scale for subsistence of local community of location k management regime l and species m
T_{klm}:	expected revenue for organisation of location k management regime l and species m

U_{klm}: utility scale for the readiness of plantation options of location k management regime l and species m
v: single deviation variable (maximum in set 16)
v_i: deviation variable i (for all 6 in set 15)

constraints:
A_{klm}: maximum area (hectare) of location k management l and species m
X_{lm}: area (hectare) assigned of management l and species m
A_{lm}: maximum area (hectare) of management l and species m
P_{lm}: expected yield for non pulp log production
D^o_{lm}: lower limit for non pulp log production of management l and species m
C^o_{lm}: upper limit for non pulp log production of management l and species m
Q_{lm}: expected yield for pulp log production of management l and species m
E^o_{lm}: lower limit for pulp log production of management l and species m
F^o_{lm}: upper limit for pulp log production of management l and species m
$G_1 ... G_6$: goal 1, 2,...6
$w_1 ... w_6$: weight for goal 1,2, ...6
$v_1 ... v_6$: deviation variable for goal 1,2, ...6

The determination of matrix coefficients for such a pay-off table is a complex process which involves experimental field data collection, extrapolation from existing data, and opinions from different expert resource specialists. Conceptually, each coefficient represents the fractional increase or decrease of a given resource if one hectare of that resource-producing forestland is subjected to a given management alternative. Dimensionally, the coefficients are generally expressed in terms of resource units per hectare. Furthermore, sufficient information is crucial for the decision-making process but is acknowledged to be particularly difficult to quantify (Cohon & Marks, 1975).

In some cases, because the quantification of the impacts of management alternatives on certain resources may be almost impossible to formulate, relative and absolute utility scales can be used to express impacts. The advantage of using relative impacts or utilities is that the coefficients obtained express general relationships between resources and management alternatives that are independent of each unit's ecological profile. Water quality and soil protection could be amalgamated as erosion control and impacts jointly measured in utility fashion (Whyte, 1995).

Objective 3 (to maximise soil protection) and objective 4 (to maximise subsistence for local community) are assessed in terms of utility measures, on a scale of +1 to +10 where 1 represents the most undesirable outcome, +5 is neutral and +10 is the most satisfactory impact. These utility assessments are hypothetically derived for general guidance in this study. Table 3.4 shows the utility measure criteria.

Table 3.4. **Utility Measure Ranges for Objectives 3 and 4**

Management Regime	Utility Measure	
	Soil Protection	*Subsistence for Local Community*
• M1 - WPPC Watershed Protection part Commercial	8 - 10	1 - 4
• M2 - HTIT Industrial Forest Plantation Transmigration	6 - 7	8 - 10
• M3 - IGT Industrial Grade Timber	1 - 5	5 - 8
• M4 - PP Pulp Plantation	1 - 5	5 - 8

For objective 6 (to maximise the readiness of the arrangement of plantation options in terms of operational technicalities such as availability of various seed quality, skilled labour supply and finance or funding), utility measures of readiness are adequate for this state of development of the research. This measure depends on the management regime and species options, and it ranges from 0 to +110 where 0 is for the lowest level of the readiness and +110 is the highest possible level of the readiness. +110 is the summation of 4 sub criteria, tecnical support (20), funding support (20), local community support (50), and prospect of interest forest enterprise involvement (20)(see Table 3.5).

Table 3.5. **Utility Measure Ranges for Objective 6**

No.	Sub-Criteria	Utility Measure
1.	technical support (0-20)	≤ 5 : not yet ready 6 - 15: ready but needs partial support ≥ 16 : ready
2.	funding support (0-20)	≤ 10 : not yet ready 11 - 15: ready but needs partial support ≥ 16 : ready
3.	local community support (0-50)	≤ 15 : not yet fully accepted 16 - 25: partly accepted via negotiation 26 - 35: accepted but needs field trial tests ≥ 36 : accepted
4.	prospects of interest forest enterprise involvement (0-20)	≤ 10 : not yet ready 11 - 15: negotiation and discussion ≥ 16 : ready

In this study, management regimes 3 and 4 (IGT and PP) were set up to the higher level of readiness than management regimes 1 and 2 (WPPC and HTIT) in terms of production priorities and the involvement of state-owned, private, or local forest companies which would be willing to take part in a long-term commitment to plantation development.

Further utility measure assessment should be derived from consultation with and inputs from several representative parties, for example, soil scientists, tree physiologists, silviculturists, watershed management scientists, sociologists, local inhabitants, and forest users. Whyte (1995) suggests that procuring a consensus scaling for utility measure needs an adequate representation of qualified and involved people.

Because of the analytical nature of these coefficients in the decision-making process that follows, the methodology for arriving at the coefficients' values should be given careful attention. Furthermore, once the optimal solutions have been obtained, the validity of these coefficients can be verified (Daellenbach et al., 1983) and at the interactive decision making stage, the coefficients can again be changed. For the purpose of this study, relative scales are utilised especially for goals 3 and 4. The degree of compatibility and interference among competing goals would have to be quantitatively measured for each individual resource management situation (Whyte, 1995).

Coefficient validity for goals 3, and 4 should be carried out for further future research. For example, for goal 3 (maximise soil protection), several researchers have done preliminary work on the relationship between different vegetation covers and soil erosion, i.e. soil characteristics and environmental impact of soil erosion under different plantation species or cover and management systems (Vos et al., 1988; Chisci & Martinez, 1993), the impact of tree species on soil productivity (van Goor, 1985), or surface erosion under different forest vegetation management (Wiersum, 1984). For goal 4 (maximise subsistence for the local community), further research should be conducted to assess the impact of such things as the tangible benefits for local communities as part of the development through employment opportunities and food subsistence through agroforestry development programs (e.g. industrial forest plantation development utilising transmigrators from transmigration projects).

Quantitative formulation of the objective function coefficients is derived from various sources and assumptions. Appendix 3.6 shows these coefficients.

The activity variables were subjected to three main constraint types: (i) area limits, (ii) minimum economic size, and (iii) individual objective functions which are finally made into constraints. The area limits are merely general constraints on the variables. The MES constraints are generated by the forestland allocation model whereas constraints from individual objectives are reformulated (Equations (21) and (22)). Figure 3.5 shows the general structure of the forestland allocation model.

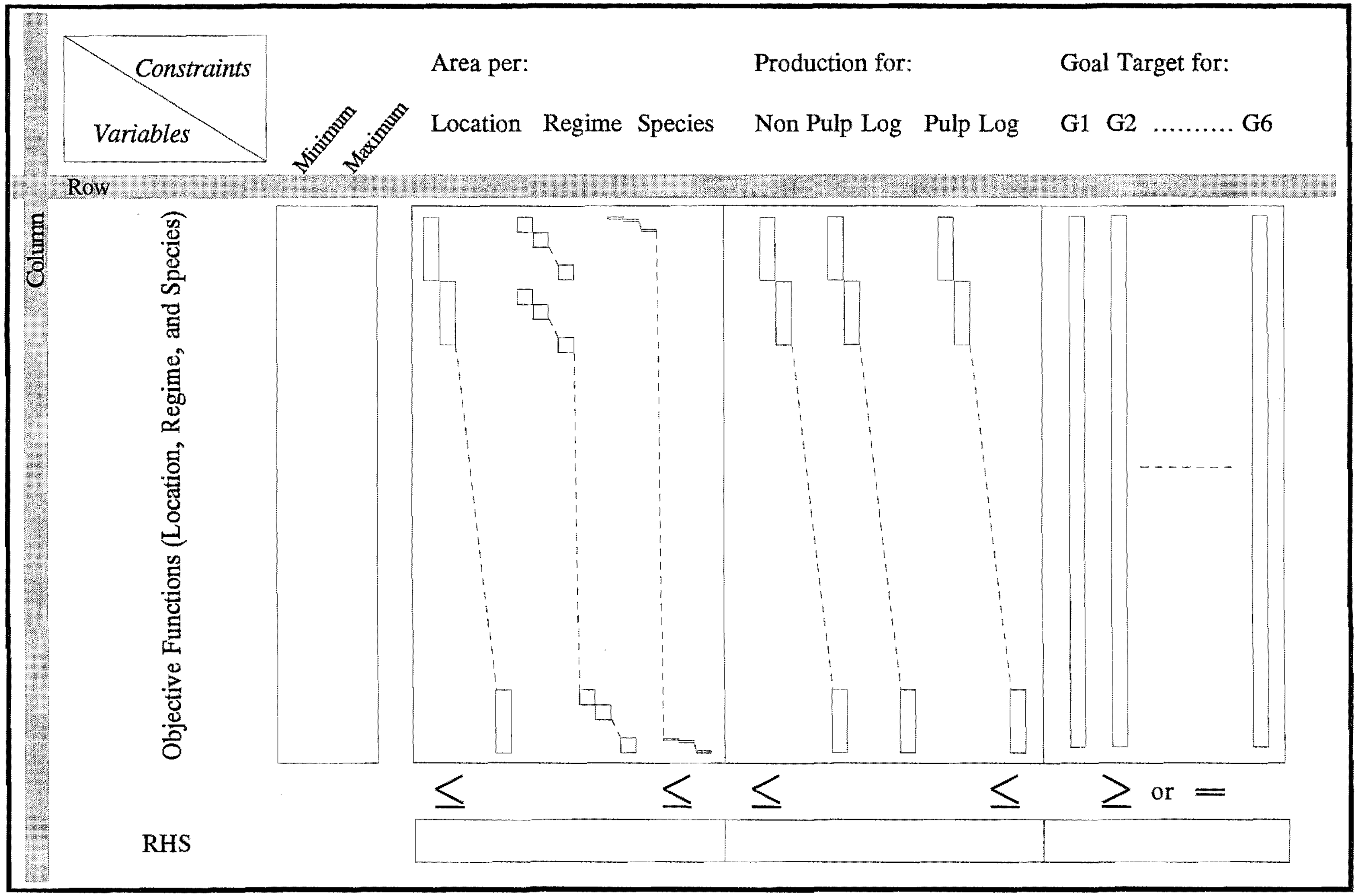

Figure 3.5. Structural Features of the Forestland Allocation Model

3.3.2.3. Solving the Goal Programming Problem

Problem formulation, matrix description and generation, optimisation, and report writing are four stages of preparing GP models to be made operational on a standard LP package to obtain numerical solutions suited to the conditions being modelled.

Two sequential tasks in GP model implementation are:

(i) the translation of GP model from the modeller's form to an algorithmic one, and;
(ii) report writing.

The first task can be done through matrix generators and/or modelling languages to produce a transitional form to facilitate translation to an algorithmic form (Fourer, 1983). The second task is transforming back from the algorithmic form to yielding various graphs and tables in the report that can be readily understandable by users.

Modelling languages which incorporate symbolic indexing and substitution at run time for large LP or GP models can be used for these two tasks. Spreadsheets or spreadsheet add-on LP packages are other alternatives for medium-sized LP models (e.g. What's Best®, Beeline®, Solver®, XA®). The model size of 8193 rows x 256 columns of a standard spreadsheets such as Quattro Pro® version 5.0 and Lotus 1-2-3® version 2.0 can be implemented in the spreadsheet. In this case, the spreadsheet is utilised as an interface between the model and the GP algorithm and as an input and output facility for providing improved communication between modeller and algorithm.

Sequential steps for spreadsheet optimisation follow:

(i) the formulated LP/GP models in the spreadsheet are saved in standard spreadsheet format (*xxx.wk1*);
(ii) the format is read by XA® and converted into algorithmic form;
(iii) it is then solved with the LP/GP algorithmic format;
(iv) the algorithmic format is read and rewritten to the original spreadsheet worksheet with the solution, and;
(v) the worksheets are retrieved in the spreadsheet environment.

The modelling system in this study uses XA as the linear programming solver. This package offers adequate flexibility for spreadsheet application. The XA® system can directly read a problem formulation from spreadsheets, and can then write the results back into spreadsheets.

For both MINMAX and MINSUM formulations, firstly the target value corresponding to each single objective for each goal on its own is found. The optimal solutions for each goal in MINMAX and MINSUM formulation are covered in detail in Chapter 4, where the background case study to explore the proposed framework is fully examined.

Implementing a forestland allocation model on a spreadsheet environment has several advantages:

(i) the models can be easily modified for new objectives and new constraints;
(ii) the models can be easily linked with other planning models (e.g. MES model);
(iii) models can be developed in tabular or matrix form according to the modeller's preference,and;
(iv) the models designed in the spreadsheet have a better chance of being understood and revised by decision makers and stakeholders in order to react to changing managerial needs.

3.3.3. **Integrated Optimisation and Simulation Models for Deliberating Preferred Solutions**

Technical forest management questions about where, what, when, and how, for example, to plant and harvest in order to manage given resources optimally require answers based on quantitative analysis and measurement. The decision-making process for both the simulation and optimisation approaches has been manipulated substantially to assist managers in forest management concerns (Bare, et al., 1984). In other words, both model approaches and their combinations have been cornerstones of important planning tools.

3.3.3.1. **Requirement Review: Existing Forest Estate Models**

Miller & Starr (1969) state two advantages of combining simulation and analytical models. These are for :

(i) higher orders of effectiveness, and;
(ii) increasing the strength of simulation system.

Jacoby & Loucks (1972) proposed a plan for a river basin by combining optimisation and simulation models. They utilise optimisation for identifying a preliminary planning solution, and then simulation for examining and modifying that solution. Furthermore, their optimisation model was formulated deliberately in a highly simplified form to be readily soluble.

FAO (1976) applied the combination of simulation and optimisation models in order to model and cater for the evaluation of forest sector development strategies in Peninsular Malaysia. Users, however, employed only the simulator capabilities (Leslie[3], *pers. comm*).

There are three existing forest estate models in New Zealand, namely IFS, FOLPI and RMS-2020. These three models are widely used within and outside New Zealand largely for

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[2] Alf Leslie was a former fellow in FAO Forestry Division and now he is a private forestry consultant who lives in New Zealand (1995).

plantation forest estates, which might involve an individual forest, or group of forests at district, regional or national levels. An additional New Zealand model, REGRAM-I is also categorised for different forest levels, but is proprietary (McGuigan, 1992; McGuigan & Scott, 1995).

FOLPI (Garcia, 1984) - the Forestry-Oriented Linear Programming Interpreter was developed by NZFRI (Garcia, 1981). FOLPI is compatible with the IFS simulator, also developed by NZFRI (Garcia, 1981).

IFS provides an advantageous arrangement for exploration and assessment of management alternatives through the allocation of the cut to crop types according to their relative increments. IFS provides various output reports. In addition, the IFS utilities are utilised to assist in the data preparation for modelling exercises. IFS reports cover (Garcia, 1981):

(i) area report displaying a table of the current areas by crop types and age classes including totals;
(ii) status summary for current area, volume, average age, and minimum relative increment - as a percentage of standing volume for each crop type;
(iii) cuts summary for area, volume, and average age for the cuts performed in the current period for each crop type;
(iv) crop report for the current status of a particular crop type in areas and volumes which are available and have been cut including the current residual area and volume, and;
(v) thinning report.

FOLPI is a specialised shell for forest estate management. It may use any several LP engines. FOLPI's fundamental strength is modelling whole forest estates and generating theoretically optimal solutions within the given constraints - aiming to develop various possible strategies. Its main uses are in forest management evaluation, yield regulation, log allocation and forest valuation. The major components of the formulation are shown in the equations below (from Garcia, 1984)).

Decision variables:
x_{ijt} : residual area in crop type i, age class j after cutting in period t which moves into the next age class in the next period
y_{ijt} : area in crop type i, age class j cut in period t
r_{ijt} : area in crop type i, age class j and replanted into crop type k
z_{ijt} : area in crop type i, age class j transferred to crop type k in period t
a_{ijt} : initial area in crop type i cut in period t and replanted into crop type k

Indices:
i $= 1...I$: crop type index
j $= 1...J$: age class index
t $= 1...T$: time period index
k $= 1...K$: crop type index
s $= 1...T$: time period index

Forms of structural constraints:

$$\sum_{j} y_{ijt} = \sum_{k} r_{ikt} \qquad \forall\ i,t \qquad (24)$$

$$\sum_{k} r_{tki} = \sum_{s=t+1}^{T+1} y_{s,i(s-t)} \qquad \forall\ i,t \qquad (25)$$

$$a_{ij} + \sum_{k} z_{kjt} - \sum_{k} z_{ijk} = \sum_{s=1}^{T+1} y_{s,i(j+s-1)} \qquad \forall\ i,t \qquad (26)$$

$$y_{tij},\ r_{tik},\ z_{tjk} \geq 0 \qquad (27)$$

The constraint in equation (25) relates the area of a crop type in all age classes that is cut and replanted into all crop types in a period. The constraint in equation (26) relates the area replanted into a crop type in a period to the area of that age class that is cut in all future periods. The last constraint (equation (27)) relates the initial area in a crop type and age class, to the area of that age class transferred into and out of the crop type in a period, and to future harvests of that age class structure.

RMS-2020 (Allison, 1984; 1989) is another computer-based forest estate model developed originally for New Zealand Forest Products Ltd (NZFP Ltd), later taken over by Carter Holt Harvey. RMS-2020 has been used extensively by these two and other organisations. Its main approach is simulation and measurement rather than optimisation. It provides a framework for forest description and forest estate measurement, for simulating future state and for state change analysis (Allison, 1986; 1985a; 1985b). RMS-2020 covers the physical management alternatives via (Allison, 1991):

(i) summary report for usage, measures, log and cashflow analysis;
(ii) general report for data listings, detailed measurements;
(iii) yield report by crop type, and;
(iv) cash report for cash flow.

The financial reports (i and iv) and yield report (iii) are important information for which decisions can be established and controlled. Selecting the management options is subjective but is able to be quantified with a neutral starting point. In addition, RMS-2020 gives more detail about log assortment in the general and yield reports. The basic crop type term was used as a consensus to associate stands and its forests (Allison et al., 1979).

In this simulator, there are two concepts of measure. Firstly, Equivalent Normal Forest (ENF) which is defined as a notional forest, the area regularly distributed among its age classes and which (Allison, 1985a):

(i) occupies the same area;
(ii) grows uniformly to a yield table, and;
(iii) has the same area distribution among age classes.

This ENF can be used in the presentation of rotation. Secondly, Normal Exchange Value (NEV) which is a related monetary measure used to provide a standard of comparison for forest value, i.e. forest states and the change measurement (Allison, 1985b).

These principal differences in reporting between IFS and RMS-2020 have led to the choice of RMS-2020 as the forest simulator in this study. The linkage facility which was then developed provides a choice of a systematic approach to industrial forest plantation planning which should enhance the quality of decision-making.

3.3.3.2. **Linkage Development**

An emphasis in this study, therefore, has been to create formal linkage between the simulator (RMS-2020) and optimiser (FOLPI) in order to explore their capabilities in a complementary way (Garcia, 1981;1986). Table 3.6 shows features of the two models. Furthermore, this technical linkage can be combined with GIS to strengthen implementable forest management strategies which best fit the capabilities of local forestland capabilities.

Table 3.6. **Integrating Linear Programming and Simulation for Regional Forest Plantation Development: A Strategic Planning**

No.	Features	FOLPI	RMS~2020
1	Concept	• Both LP and simulation are concerned with building a model for describing the interrelations of components of a system. • Both models are approximate because the mechanisms used in them are simplifications, to make the models usable. • Both models are forest estate models.	
		• FOLPI (LP) in which the essentially combinatorial nature of the problem executes the mandatory algorithmic approach optimally. • For optimisation, it is sufficient to allow resource transfers at the beginning or at the start of the planning horizon.	• RMS (simulation) allows for dynamic systems and traces their history. The interest lies in the movements and changes in a system, albeit because the final output of concern is some global measure of its history over time. •In a sense, optimality is still the goal, since by subjective experimenting we hope to discover the best way of managing a system. But there are no built-in algorithms that lead to an optimal solution. •Simulator transfer could be allowed in any period.
2	Harvest schedule	• FOLPI (LP) provides a quick way of investigating alternative harvesting strategies (as a benchmark analysis).	
3	Solutions or outputs	• FOLPI (LP) analyses are used to identify the general direction for managing various parts of a plantation forest.	• RMS analysis moves away to search for a practically expedient "optimum" that allows a solution to be implemented for problems facing forest management.
		• In other words, best results would be obtained by applying first an LP-based system, and then using the simulator to explore the effect of deviations from the "optimal" solution.	
		• FOLPI (LP) seeks a "best" solution iteratively subject to constraints. Its outputs can be used as a point of departure for exploring alternative futures through RMS simulation. • Conflicting objectives are sometimes inherent in a problem. The optimal solution (i.e. harvesting schedule) depends, of course, on the relative importance assigned to the conflicting objectives.	•RMS simulations enable a manager to evaluate: 1.the impact of specific strategies by trial and error. 2.comprehensive assessment of the effects of different development strategies.

Table 3.6. (*continued*)

4	Approach	• FOLPI (LP) management strategy is an output	•RMS management strategy is an input by the user.
5	Flexi-bility	• FOLPI (LP) as an optimisation method forces modellers to design models in very specific forms.	•RMS simulations allow much more flexibility in modelling. Any phenomenon that can be represented by mathematical relationships of any form is traceable by simulation
6	Draw-backs	• The objectives and constraints used in optimisation models are often gross oversimplifications & many relevant factors that are difficult to quantify are ignored. • FOLPI" (LP) major disadvantage is the necessity to specify a single objective function for multi-ownerships or multi groups. However, it should be noted that as the model becomes more heavily constrained by the complex of management strategies placed on each ownership, the model has less choice in achieving an "optimal" solution. Hence, the model depends more on further simulation and less optimisation, with the choice of objective function less critical in practical terms.	• RMS (simulation) ENF measurements (crop type 1 as standard regeneration) keep changing every period. Therefore, it should be used as a guidance measurement only.
		• Different input data and report files.	
7	Advan-tages	• Instead of 'goal-programming' approach (area base), FOLPI (LP) and RMS (simulation) allow any total future land-base compositions for plantation incorporated in the regional planting plans. It assumes that a future land-use plan has been conducted or is in the form of a output from another system. • Increase the relative strength of both models. Douglass (1995) finds that both models can be usefully employed to model multi-crop production and yield systems provided that the crop yields can be expressed in either area, volume, weight or revenue terms. • Both models provide a choice in the systematic approach for strategic planning which should improve the quality of decision making. • Optimisation & simulation are complementary, rather than competitive approaches.	
8	De-cision level	• FOLPI (LP) involves top-level managers or decision makers (its important feature for this application)	• RMS (simulation) involves top, middle and low-level managers or decision makers
9	Internal limits (as they now stand)	• Maximum age classes: 99 • Maximum # periods: 99 • Maximum # products: 20 (product file) • Maximum # products: 12 (thinnings file) • Maximum # products: 8 (plan file)	• Max. age classes: 60 (but can be relaxed). • Products of age classes 32 crop type is the limit.

The ability to adjust any conventional difference between these two models offers a two-way linkage opportunity. It needs a 2-year interval for RMS-2020 to be compatible with the FOLPI period convention, i.e. year 0 for land preparation and year 1 for planting. Period convention differences are listed in Table 3.7. Technicalities are shown in Appendix 3.5.

Table 3.7. **RMS-2020 and FOLPI Period Conventions**

Period (Year)	RMS-2020			FOLPI		
	age class	age	activity	age class	age	activity
0 (1995)	0 (31 March)	none	adjusted to FOLPI	0 (31 March)	none	land preparation
1 (1996)	1 (31 March)	0	planting	1 (31 March)	0	planting
2 (1997)	2	1	tending, *etc*	2	1	tending, *etc*
3 (1998)	3	2	*etc*	3	2	*etc*
... (....)	...	...	...	...	...	...
n (....)	*n*	*n* -1	*etc*	*n*	*n* -1	*etc*

Technical sequences in this linkage:

1. Data tables are built to describe the forestland base (in this case, crop type). Figures 3.6.A,B,C and D show the overall linkage structure. The first linkage consists of three phases:

   (i) to produce Genrep file from RMS-2020, then;
   (ii) to transfer the data file from Genrep file to a FOLPI input file for area, yield, log class and price (i.e. area, yields, products and thinning files; with the 'dat' extension) by utilising a transfer utility. Figures 3.6.A and 3.6.B describe these detail phases.

2. The second linkage involve 3 phases:

   (i) to generate FOLPI summary and status files on which the data files were based from RMS-2020 data, then;
   (ii) to transfer summary files to RMS-2020 utilisation commands (i.e. command 470 and command 471) by applying a transfer utility, and;
   (iii) to adjust technical requirement, period conventions, management practicality and sensitivity analysis in the RMS-2020 description file. Figures 3.6.C and 3.6.D show this step.

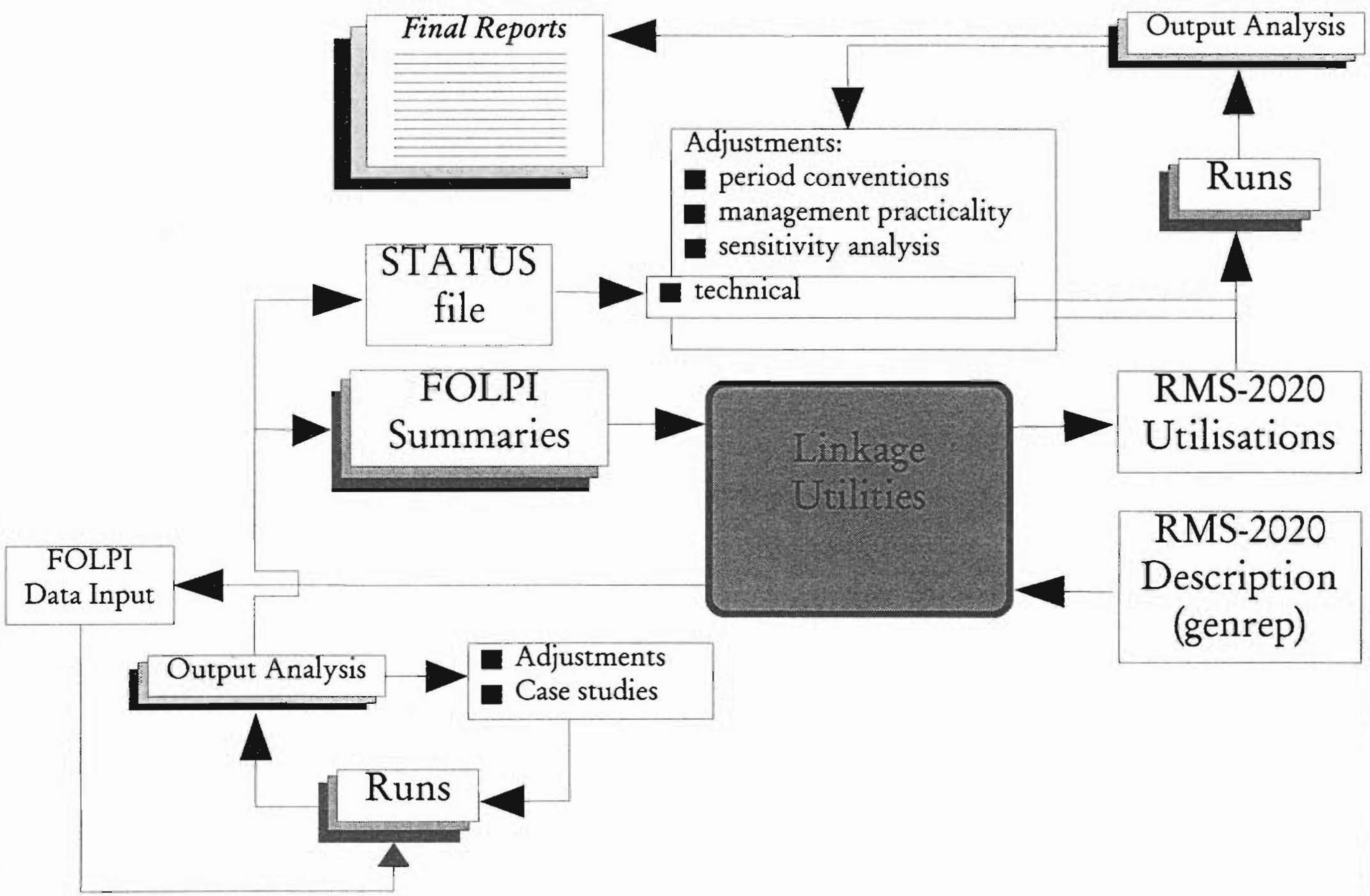


Figure 3.6.A Interface Applications between FOLPI & RMS-2020:

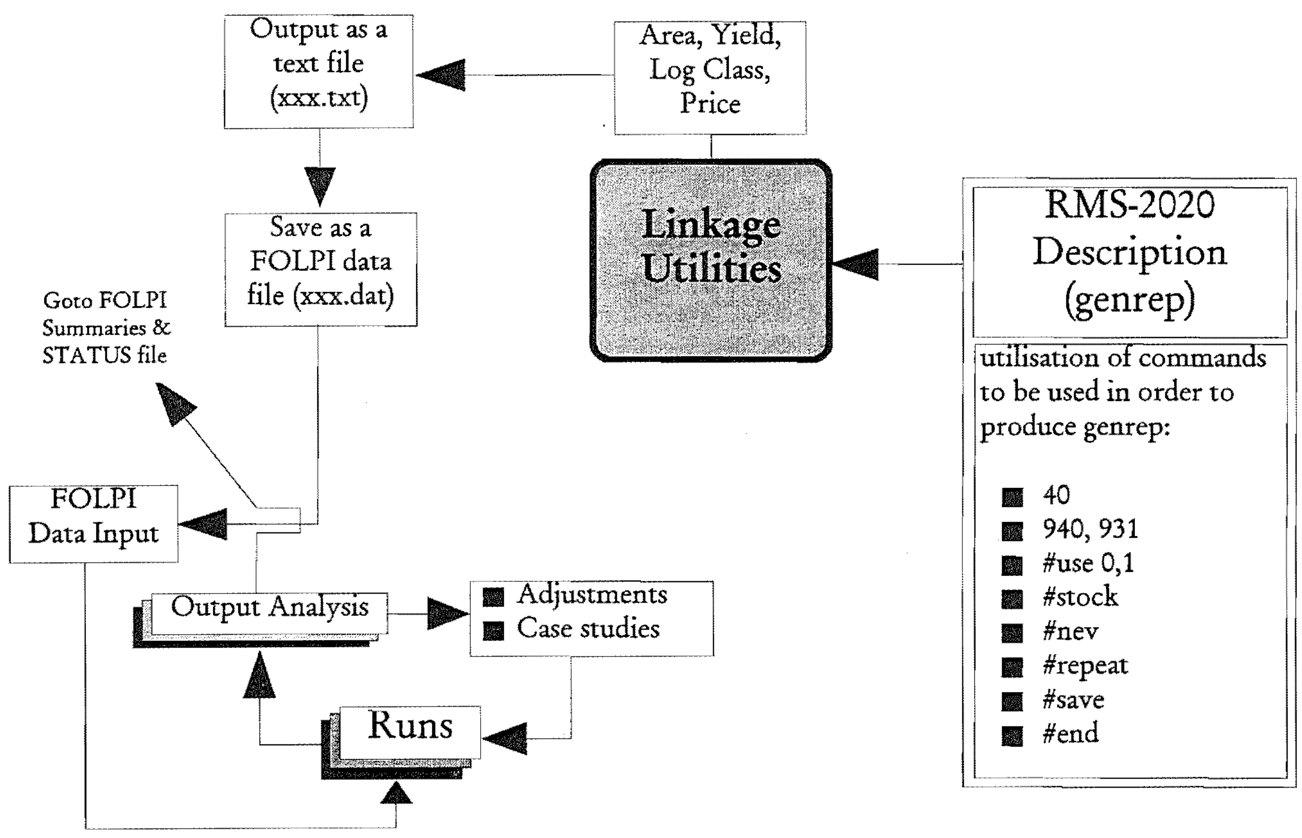


Figure 3.6.B. Technical Flow Diagram from RMS-2020 to FOLPI

These two transfer utilities are developed in macro format for Quattro Pro® version 5.0 (Borland, 1994). The background case study was carried out and linkage outputs were shown in Chapter 4.6.

3. Inputs and consequences can be presented visually via GIS (Mapinfo, 1993).

4. If, for example, a harvest quantity cannot be totally redistributed, the maximum feasible harvest level is calculated for each crop type, sequences 1 and 2 were reiterated or repeated then sequence 3 (maps and reports) were carried out in order to depict the crop type redistribution.

3.3.4. Spatial Modelling and Database

The ability to transform spatial database analysis into a variety of prescriptive and/or descriptive map and tabular outputs makes more informed decision making possible (Jordan, 1993).

There are two approaches relating to the GIS:

(i) the GIS as a mapping tool representing model outputs (as GIS database), and;
(ii) the GIS as a spatial database modelling tool.

The first approach is used in this study, and shows primarily the spatial effects of:

(i) forestland allocation, and;
(ii) forest management strategies.

In other words, the purpose of GIS is to help this decision making process, comprehend the forestland allocation and forest management philosophy, and recognise that those forest resources and other natural ones are combined and associated through complex interrelationships. Furthermore, GIS enables , in this case decision makers and stakeholders, to understand resource relationships on forestland and crop type better and contribute to more informed spatial decisions.

The second approach is spatial modelling through GIS where the model treats in this case forests as spatial entities and uses geographic distribution of stand development types and stages and their modification over time.

In both approaches, the quantitative improvement in the speed of analysis has provided the means to change the way the analysis of GIS can be approached via integrating multiple data sets efficiently. Since re-analysing the GIS database is relatively inexpensive and can be rapidly executed, complex planning scenarios can be progressively modified by reanalysing the plan to assess proposed changes.

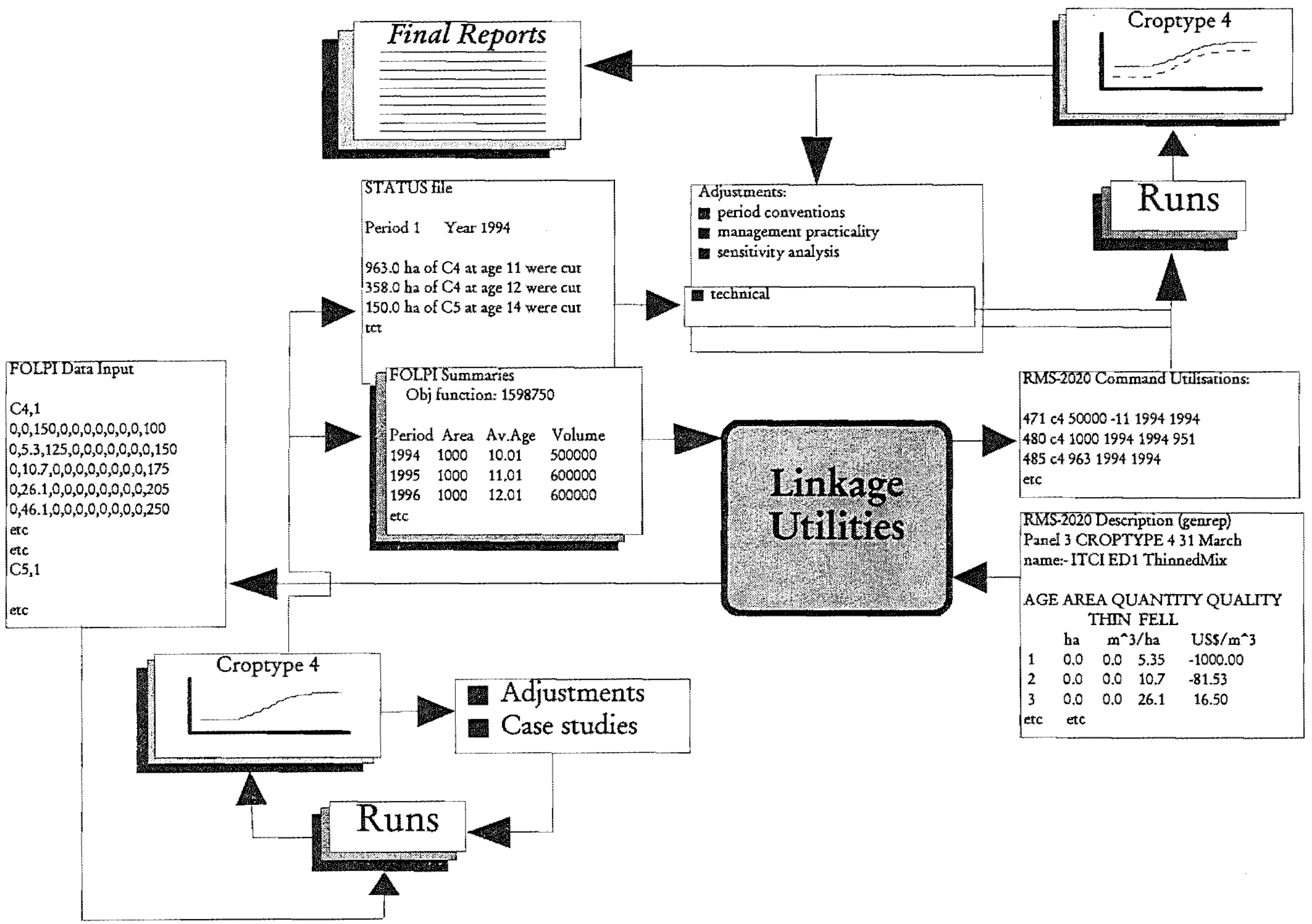


Figure 3.6.C. Interface Applications between FOLPI & RMS-2020: Detail

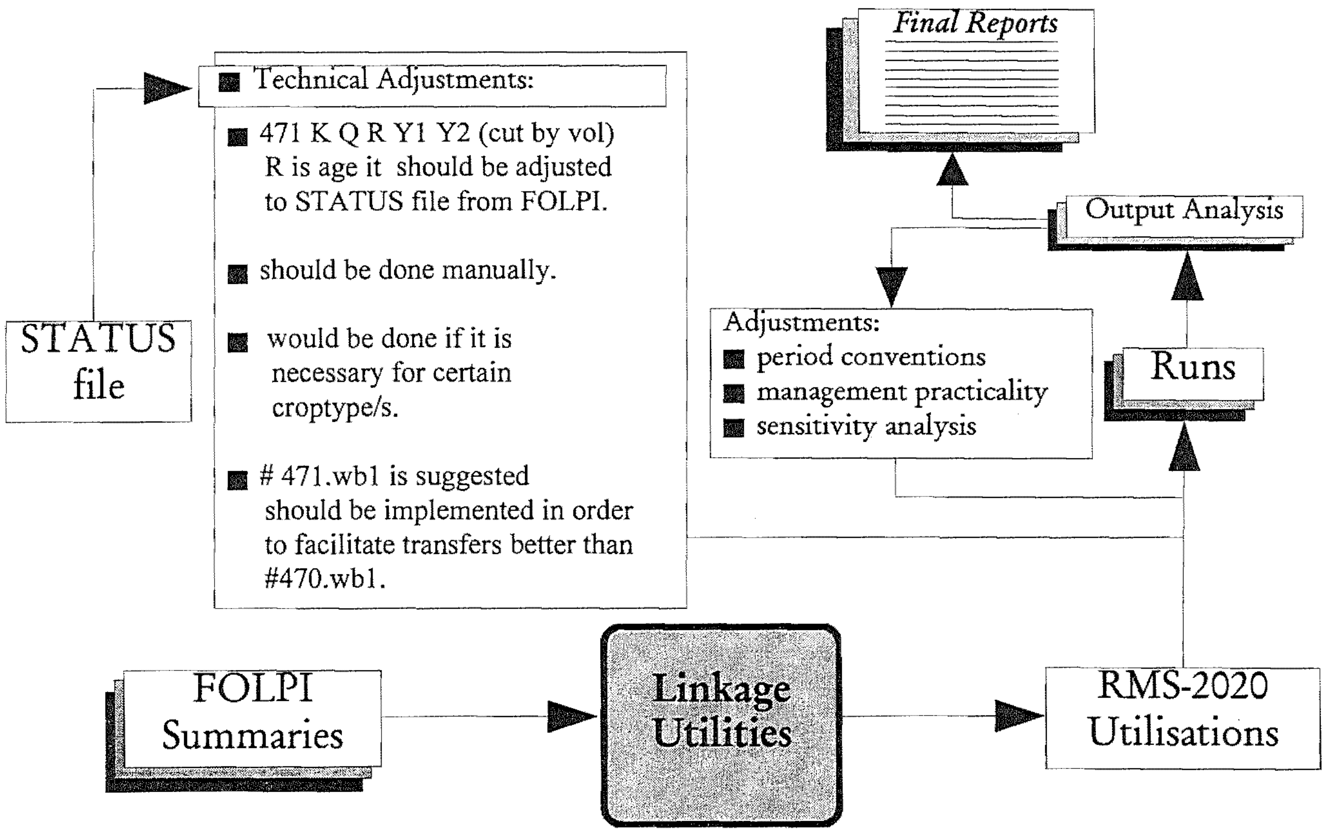


Figure 3.6.D. Technical Flow Diagram from FOLPI to RMS-2020

The focus of forest management is not only just for wood supply but also for other purposes such as landscaping. Creating and maintaining long-term plans requires negotiation on the design and implementation in terms of amounts, timing, and location. GIS facilitates a technical support for mapping procedures. Mapinfo version 1.0 (1993) is used in the case study (Chapter 4). This system can be utilised at any level of planning but is crucial during communicative decision processes. This software has been developed for a desktop mapping capability. Visualisation and geographic analysis have emerged as premier needs. East Kalimantan region is selected as a case study region.

3.3.5. **Data Requirement for the Planning Systems**

The framework and results at this stage should be regarded as only preliminary, because some data are still incomplete and unrefined. Reliable data on the environment and natural resources, and processing knowledge, still cannot keep up with the technology (Power, 1994).

Understanding and knowing the current resource condition and monitoring its development are important to this planning system to managing the industrial forest plantation development. For example, the fourth step in the proposed planning system is the linkage between optimisation and simulation models which would generate substantial databases. For example, spatial data information that would allow a GIS information retrieval system (total non pulp log production for any given planning periods or for any given types of location, management regime or species).

On the other hand, it is crucial to review regulations, acts, rights, or local agreements with a broad perspective in order to capture the essence of those legal concerns within the planning system requirements.

This study must be viewed, therefore, as a description of methodology and an indication of the feasibility of generating desirable results rather than as a specific policy and quantitative recommendation. In addition, real-time decision-making often requires real-time data procurement and communications.

Chapter 4. Background for Using The Planning Systems: A Case Study

All objectives are subjective (R.J. Betts)

4.1. Background

This chapter explains the use of formal multi-objective analysis for integrated planning mechanisms relating to industrial forest plantation development at a regional level. The main objective of the study was to develop a methodology for analysing strategic options for industrial forest plantations that can characterise the essence of seeking consensus, through effecting trade-offs between conflicting objectives and evaluating derived options in terms of spatial and transportational consequences or considerations.

The planning system developed here is applied to a regional case study problem, to demonstrate and test its potential. Data for the case study were collected, modified and adjusted from various sources and used to formulate a typical planning problem in industrial forest plantation development. The case study problem is described and the results of applying the proposed planning approach to the problem are presented.

Section 4.2. provides an overall view of the planning problem, which comprises a regional planning framework with three basic components, namely minimum economic size for particular management regimes, forestland allocation, and LP-Simulation linkages. The following three sections provide more details for each of these major components in turn.

4.2. The Regional Planning Problem

Forests are undoubtedly important in providing extensive benefits at local, national and global levels, particularly nowadays, and especially where some of these benefits depend on the forest being subject to minimal interference or subject to full harvesting for wood and non wood products (FAO, 1993). Furthermore, forests are still at the centre of a problem of conflicting interests. Such interests include local communities, loggers, concessionaires, forest industries, central or local governments, and NGOs.

Before the 1970s, Indonesian tropical forest resources, mainly in natural forests, were in great abundance, the effects of their utilisation were relevantly insignificant and were substantial only regionally. Twenty years or so ago, utilisation reached certain limits that changed this pattern.

This limitation to forest resource can be as a consequence of (ADB, 1987; FAO, 1993; ITTO, 1990):

(i) nature;
(ii) recent policy and regulation changes, and;

(iii) incremental growth of land-use patterns other than forestland-use.

The starting point for this study refers to a statement by FAO (1993; p.56) to the effect that

> *"If any type of forest is to be sustainably managed, the people and the countries concerned must be convinced that the land will remain more valuable under forest than another form of land-use. It will be necessary to find the means to assess the value of the forest accurately in monetary terms and to develop techniques to compare this value with that of alternative forms of land use."*

Many studies in forest sector modelling have dealt with one or more considerations of forest resource management, mainly in quantity (supply), quality, and demand. Until recently very few studies have been undertaken to address the majority of the components making up the decision-making process.

In forest sector modelling, for example, it is possible to integrate changes in land-use and changes in forest management with the production of non-wood outputs such as wildlife, water, and fish (Joyce et al., 1992). But it is not easily formulated and interpreted by the decision makers (Haynes and Harou, 1992). In this study, an integrated modelling approach incorporating such facets was utilised for practical purposes. MES and forestland allocation models were developed independently, but they were able to be linked. In addition, these two single models were technically useful for addressing specific considerations that can in turn help in the decision-making process.

The forest planning process for Indonesia's forests and public forestlands has become increasingly and unduly complex over the last two decades. New regulations and decrees have been set up in order to address system concerns and values with regard to the wood and non-wood forest products, services, and factors involving the production process from forestlands. Furthermore, two fundamental philosophies, i.e. sustained yield and multiple use, including their integration into a systematic approach to forestland-use planning and practical forest management, provide the focus for managing those forestlands (MoF, 1993). The two most important concepts to be introduced into current policies are:

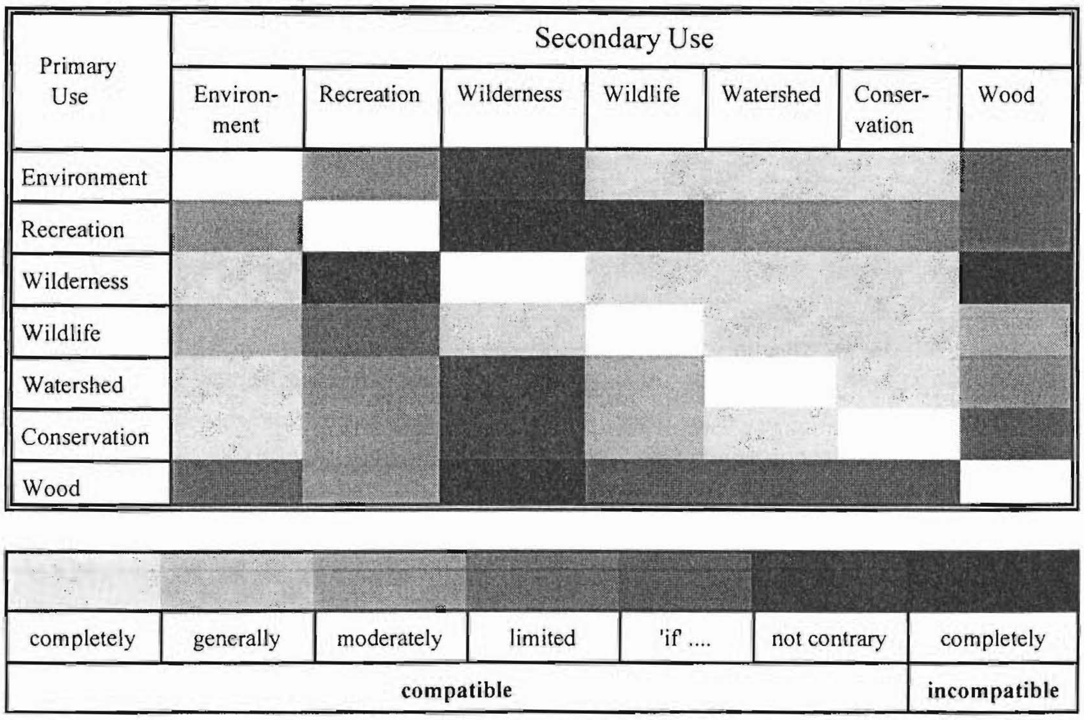
(i) the need to secure people's participation in resource management - including participation in the policy-making or decision-making process itself - while confirming resource sustainability, and;
(ii) coordination of the decision-making process.

One aim of forest planning is to ensure that all forestlands, destined to form industrial forest plantation developments, should contribute as wide a range of outputs as possible, consistent with the selected land-use purposes of the area. Clawson's matrix (Clawson, 1975) should be considered if multiple use is both desired and unavoidable (see Table 4.1). Different functions where circumstances can be compatible or incompatible are shown in Table 4.1.

Smith (1994) summarises whether forest plantations have:

(i) positive effects on soils, such as soil improvement via increased nutrient availability and soil physical improvement, or;
(ii) negative effects such as reduced soil quality leading to soil nutrient imbalances or depletion and reduce site productivity due to soil compaction and erosion when machinery was used during site preparation, establishment and harvesting. These summaries have relevant implications to what extent that those four single or combination of management regime options affect the forestland allocations. The crucial point is not only the impact severity, but the extent to which it is irreversible (Clawson, 1975).

Table 4.1. **Compatibility of Forest Uses**



Regarding Clawson's table, Smith's summary, and to the wider extent that modification of it is appropriate, one might deduce, for example:

(i) non-pulp plantation regimes can provide simultaneously for sustained yields of non pulp logs, subsistence of locals (through labour opportunities), and most forms of soil or sedimentation stability, or;
(ii) watershed plantation regimes are mainly for soil protection while their harvests are tolerable and possible, thus demonstrating one example of compatibility.

When there is more than one forest use there is either no difficulty of management between compatible uses or else problems exist regarding how to balance the output among the forest uses (Clawson, 1975). Forestland-use becomes complex when demands on the same forestland conflict and cannot be exercised simultaneously. The decisions in these situations can be solved by priority usage or balanced usage to prevent or minimise conflict. Many of these competing claims did not emerge in the past, but now in much of the present developing world, forestlands are the only source of lands for, for example, new agricultural land (FAO, 1993); or for transmigration settlements. Deciding on what should and can be done in each situation should include dialogue, compromise and conciliation. Furthermore, the analytical and the political or decision making aspects of planning cannot in general be segregated (Bogetoft and Pruzan, 1991).

The role of strategic decision planning is to decide on the allocation of resources available to enterprises (Gunn, 1991). Enterprises addressed in this study can be categorised into two levels:

- forestlands designated for various plantation regimes, both state and privately owned forest companies;
- production capacity decisions in wood processing plants, mostly private enterprises and comparatively few state-owned forest companies.

In addition, the strategic planning system is designed to assist in the establishment of long-term policies for regional industrial forest plantation development. In particular decisions of interest are:

1. determining sustainable forestland allocations for different plantation regimes;
2. estimating the minimum economic profitable size for any given plantation management regime, species, and location;
3. demonstrating and testing the feasibility of utilising the proposed framework in one specific location and applied to forest plantations:

- MES model covers all possible management strategies and species;
- Forestland model includes all possible spatial locations;
- Integration between LP and simulation refers to one specific location.

Regional resource planning and decision-making for industrial forest plantation development increasingly involves participation of the public. The theoretical framework outlined here provides a basis for analysing conflicts among and within groups of people who often ignore communicative aspects of planning. In other words, it is for anticipating conflicts through forest resource planning. Motivation to maximise or minimise the degree to which those groups can satisfy their individual objectives should involve recognition of outcomes arrived at in a consensus decision-making environment.

The required planning decisions should be considered in terms of robustness for an integrated planning system and capability for being utilised to generate compromise and feasible plans for diverse locations, management regimes, species options and trade-offs. They should also have a capability to characterise the main planning problems in choosing plantation regimes in response to changing consensus decision mechanisms and market environments.

4.3. **The Criteria for The Case Study**

A technical framework for describing industrial forest plantation options quantitatively was developed through six steps (see Figure 3.4; p.61), namely:

Step 1: minimum data and information required for developing and utilising planning models were collected, sorted and supplied.

Step 2: MES spreadsheet-based models were run for data relating to various species and under different management regimes.

Step 3: forestland allocation, a spreadsheet-based MODM model, was run to derive several industrial forest plantation development options for six different objectives:

objective 1: to maximise non pulp log production (000 m^3)
objective 2: to maximise pulp log production (000 m^3)
objective 3: to maximise soil protection (util)
objective 4: to maximise subsistence (util)
objective 5: to maximise revenue from forestland for organisation (NZ$000)
objective 6: to maximise the arrangement readiness of the plantation development (util)

Discussions and communications can begin after completing this step.

Step 4: crop type allocations were made in anticipation of spatial consequences of model outputs which could then be utilised when linking LP and simulation models:

a. optimisation (LP) models were solved in order to derive several solutions to meet individually constructed objectives, and;
b. simulation models were run in order to adjust long-term preferred solutions in terms of log assortments, financial structures, and other considerations not included formally as constraints in (a).

Step 5: a spatial database (in GIS) was generated from simulation model outputs which provided:

a. solutions which need further modifications to or refinements of objectives and spatial interactions; or
b. deliberated preferred solutions recommended as final development options for industrial forest plantations.

Step 6: the deliberated solutions were implemented and monitored.

The case study area is located in East Kalimantan, Indonesia, a region which has been playing an important role in the forestry sector at both regional and national levels. A freehand map of the region was drawn to show the breakdown of the forest resources into crop types, each of which represents some function of location, management regime and species (see Figure 3.3).

In principle, the framework could become multi-temporal by creating each variable in time-dependent fashion. Simplicity and clarity are essential characteristics of a strategic planning model to facilitate a communicative decision-making process. In this case the model is structured as a general integrated deliberation of planting, harvesting, product manufacturing and marketing strategies. Furthermore, the merit of the process ultimately determines the consequences of implementing the framework and thus the success or failure of the framework.

4.4. **The Minimum Economic Size Model: Results Obtained**

The following financial analysis is used to determine in general the minimum economic area needed to establish profitable plantations in the East Kalimantan region. NPV per hectare and IRR methods are applied.

As in evaluating forestry investments, the selection of discount rate is critical in determining the scope and type of program (Guttenberg, 1950; Gregersen & Houghtaling, 1977). Its selection influences directly the value of plantations and it should be selected appropriately. The combination of acquired knowledge, experience, and large-scale effort makes the over-all risk for a given program insignificant (Guttenberg, 1950). In this study the term discount rate always refers to real rates unless explicitly stated to the contrary. Table 4.2 shows several sources for various discount rates.

Table 4.2. **Discount Rate Sources**

No.	Sources	Discount Rate (per cent)	Note
1.	Priasukmana (1984)	6	6 per cent is a low discount rate and 10 per cent is the upper discount rate used by governments to justify public projects (Sedjo, 1987).
2.	Sedjo (1986)	6 - 10	
3.	Fraser (1987)	1 - 10	

The focus of the real discount rate for this study is 8 per cent which is above the low discount rate (at 6 per cent) and below the upper (at 10 per cent). The choice of discount rate has a major influence on the MES outputs. In this case, a higher discount rate would prefer MES with larger sizes. On the other hand, a lower discount rate favours smaller MESs.

Table 4.3 shows the list of species and minimum size (hectare) in order to achieve threshold IRR (at 8 per cent to correspond with NPV benchmark).

Figures 4.1, 4.1.A, 4.1.B, and 4.1.C, and Appendices 4.1, 4.2, 4.3, and 4.4 show the comparison of IRR, NPV per ha (at 8 per cent discount rate) and total cost per hectare by different plantation size for the base case, then sensitivities 1, 2 and 3 respectively and indicate that:

1. the IRR increases throughout the range of given plantation sizes, i.e. the keypoint is a consistency in rapid increase in IRR from 5 000 - 20 000 ha, thereafter falling off (see Figures 4.1 and 4.1.A);

2. the financial analyses indicate that the larger plantations provide large NPVs per ha based on representative input costs and output prices, and;

3. the larger plantations tend to yield a lower total cost per hectare. Total costs consist of general cost proportion, i.e. 1.5 per cent for nursery cost, 24 per cent for establishment cost, 5.5 per cent for fire and disease protection costs, 28.7 per cent for roading, and 40.3 per cent for administration costs.

The base case results in negative NPVs per ha (at 8 per cent discount rate): for example, for M_1S_1 option (Appendices 4.1.a and b), 5 000 ha ($-277 ha^{-1}), 10 000 ha ($-98 ha^{-1}) and 20 000 ha ($-9 ha^{-1}) plantation sizes. IRR's of 5.7 per cent, 7.0 per cent and 7.9 per cent are obtained for these 3 plantation sizes. The over-all ranges for the IRR for all plantation sizes are between 5.4 per cent and 10.2 per cent (Appendix 4.1.a, Figures 4.1.A.(i), and 4.1.B.(i)).

The first sensitivity (i.e. all costs increasing at 3 per cent) yields negative NPVs per ha (at 8 per cent discount rate), for M_1S_1 option (Tables 4.5.a and b), 5 000 ha ($-312 ha^{-1}), 10 000 ha ($-134 ha^{-1}), 20 000 ha ($-45 ha^{-1}), and 30 000 ha ($-15 ha^{-1}) plantation sizes. The IRRs of those plantations are 5.4 per cent, 6.7 per cent, 7.5 per cent and 7.8 per cent respectively. The other larger plantations (for M_1S_1) result in positive NPVs and acceptable IRRs. The IRR ranges between 5.1 per cent and 9.9 per cent for all plantations (Appendix 4.2.a, Figures 4.1.A.(ii), and 4.1.B.(ii)).

The second sensitivity (i.e. non pulp log prices increase at 0.3 per cent annually and pulp log prices increase at 0.1 per cent annually) indicates that, for example, for M_1S_1 (Appendices 4.3.a and b), every plantation size considered yielded positive NPV per ha and acceptable IRR except for 5 000 ha ($-218 ha^{-1}) and 10 000 ha ($-40 ha^{-1}). The IRRs of these two plantation sizes are 6.2 per cent and 7.6 per cent respectively. The over-all IRR ranges are 6.0 per cent and 10.7 per cent for all plantation sizes (Appendix 4.3.a, Figures 4.1.A.(iii), and 4.1.B.(iii)).

Table 4.3. **Species List with Minimum Size, IRR, NPV and Total Cost per Hectare**

Management Regime	Case	Species	Size (ha)	IRR (%)	NPVha^{-1} ($ha^{-1})	TC ha^{-1} ($ha^{-1})
WPPC	BC	A. falcataria	30 000	8.2	20	3 428
		D. latifolia	30 000	8.1	17	4 119
	1	A. falcataria	40 000	8.0	0	3 493
		D. latifolia	50 000	8.0	3	4 190
	2	A. falcataria	20 000	8.5	49	3 464
		C. calothyrsus	20 000	8.4	41	3 440
	3	A. falcataria	20 000	8.1	14	3 548
		C. calothyrsus	20 000	8.1	5	3 523
HTIT	BC	E. deglupta	20 000	8.2	20	3 746
		A. falcataria	20 000	8.2	19	3 777
	1	E. deglupta	30 000	8.1	13	3 803
		A. falcataria	30 000	8.1	12	3 835
	2	E. deglupta	20 000	8.7	86	3 746
		A. falcataria	20 000	8.7	86	3 777
	3	E. deglupta	20 000	8.4	50	3 837
		A. falcataria	20 000	8.4	50	3 869
IGT	BC	E. urophylla	10 000	8.8	116	3 850
		G. arborea	10 000	8.2	33	4 291
	1	E. urophylla	10 000	8.5	80	3 941
		G. arborea	20 000	8.5	84	4 280
	2	E. urophylla	5 000	8.1	13	4 053
		G. arborea	10 000	8.5	89	4 291
	3	E. urophylla	10 000	9.0	150	3 941
		G. arborea	10 000	8.3	51	4 393
PP	BC	E. urophylla	40 000	8.1	13	3 692
		E. deglupta	40 000	8.1	11	3 689
	1	E. urophylla	90 000	8.0	1	3 754
		E. deglupta	100 000	8.0	1	3 752
	2	E. urophylla	20 000	8.3	34	3 743
		E. deglupta	20 000	8.3	32	3 740
	3	E. urophylla	30 000	8.2	26	3 800
		E. deglupta	30 000	8.2	25	3 797

Notes: BC: base case; 1: sensitivity 1; 2: sensitivity 2; 3: sensitivity 3; TC: total cost.

The third sensitivity considers a combination between a 3 per cent increase in all costs (sensitivity 1) and non pulp log and pulp log prices increase 0.3 per cent and 0.1 per cent annually respectively (sensitivity 2). It results, for example for M_1S_1 (Appendix 4.4.a), in a decline in the IRR below 8 per cent for 5 000 ha (i.e. 5.9 per cent) and 10 000 ha (7.3 per cent). Other plantations give acceptable IRRs which are greater than 8 per cent. The NPV per ha figures also give, the same pattern as indicated in the IRRs and positive NPVs per ha. The IRR ranges between 5.9 per cent and 10.4 per cent all reflect plantation size variations (Appendices 4.4.a, 4.4.b, Figures 4.1.A.(iv), and 4.1.B.(iv)).

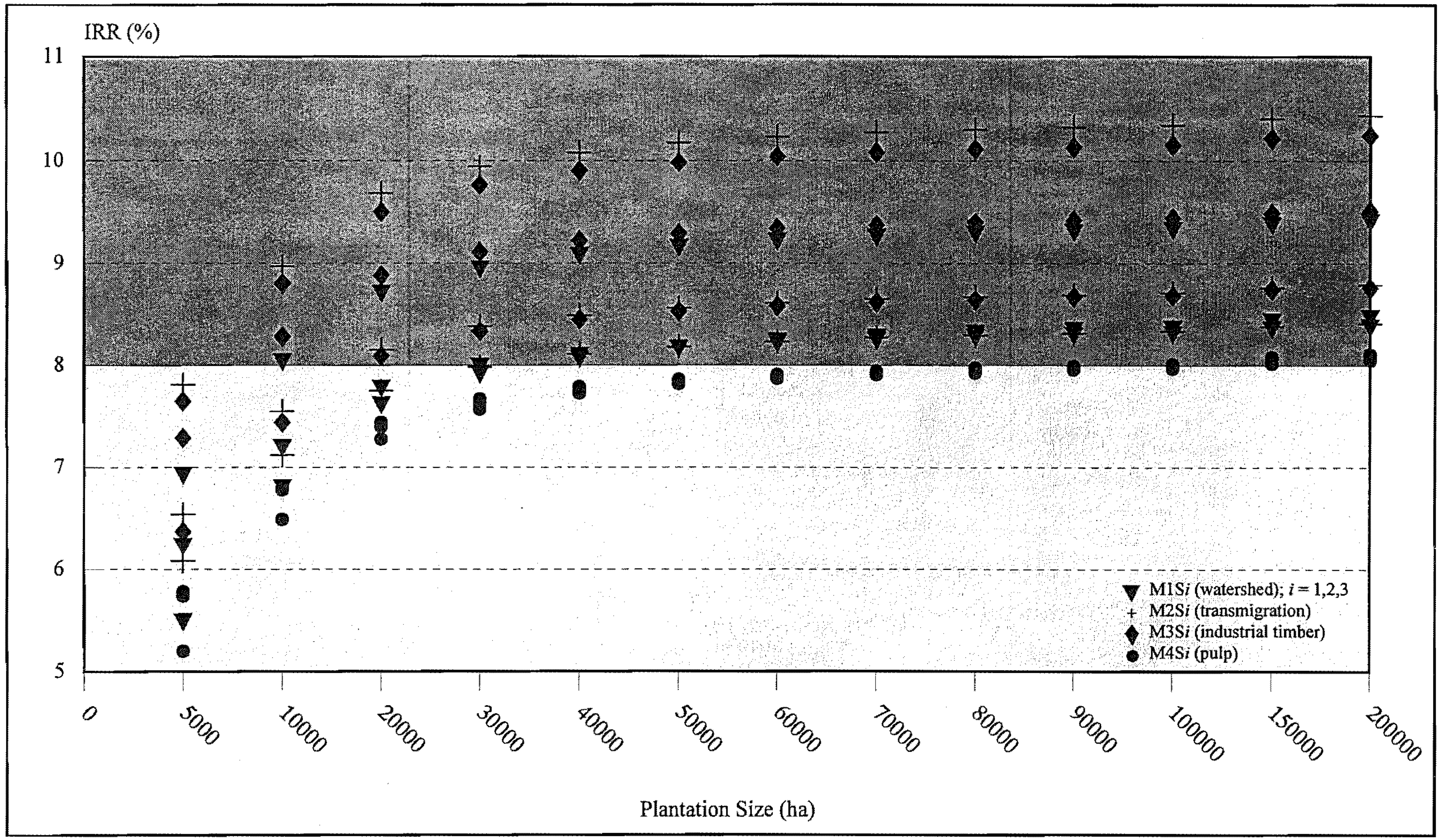
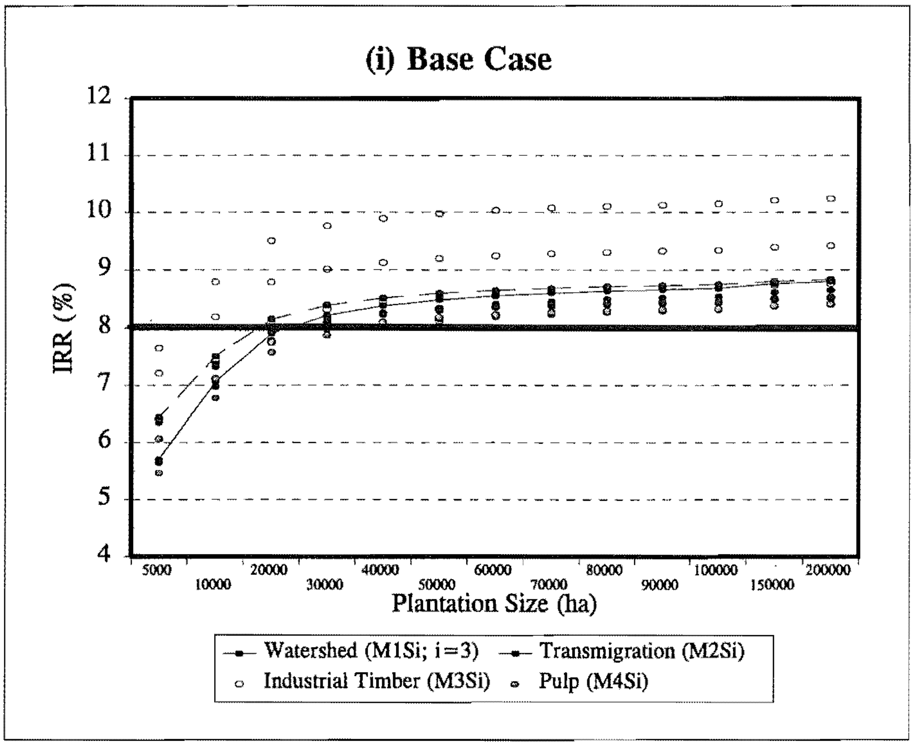


Figure 4.1. Financial Analysis: IRR Summary



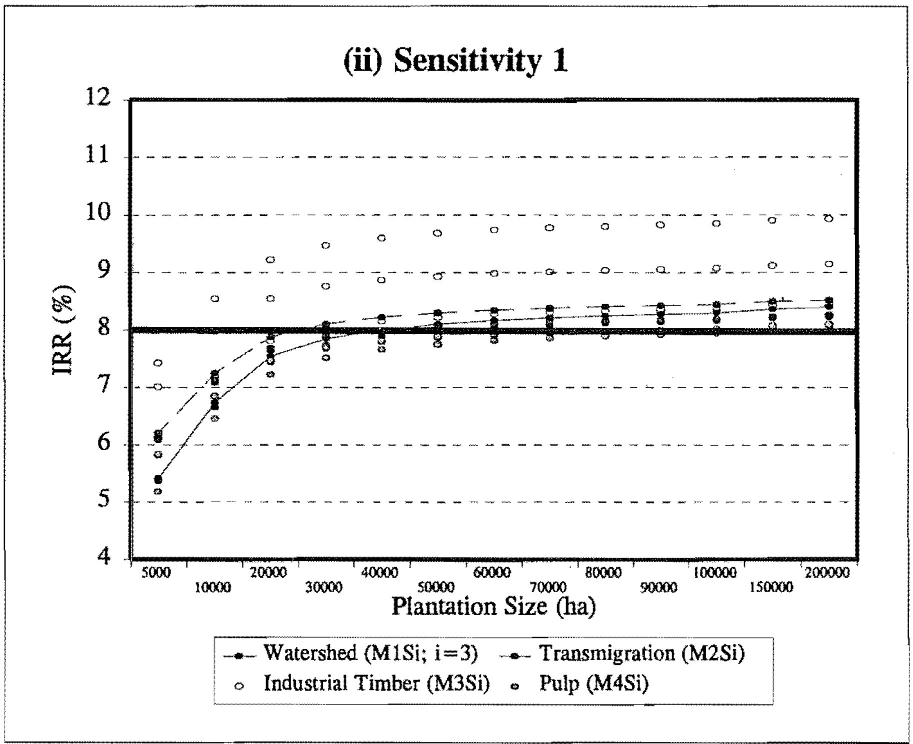
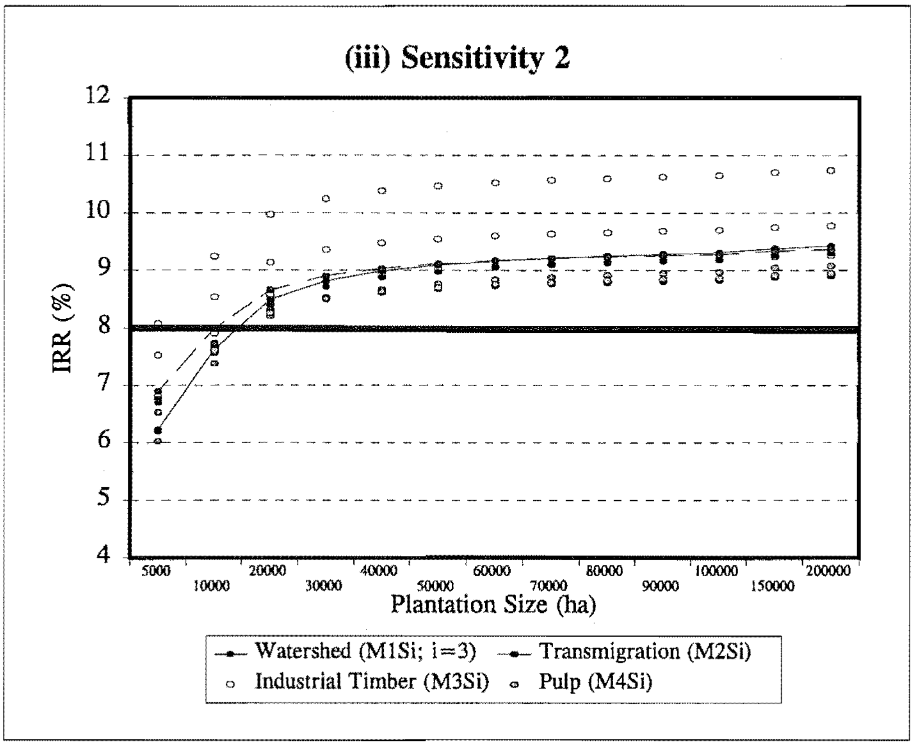


Figure 4.1.A. IRRs Comparison by different Plantation Size



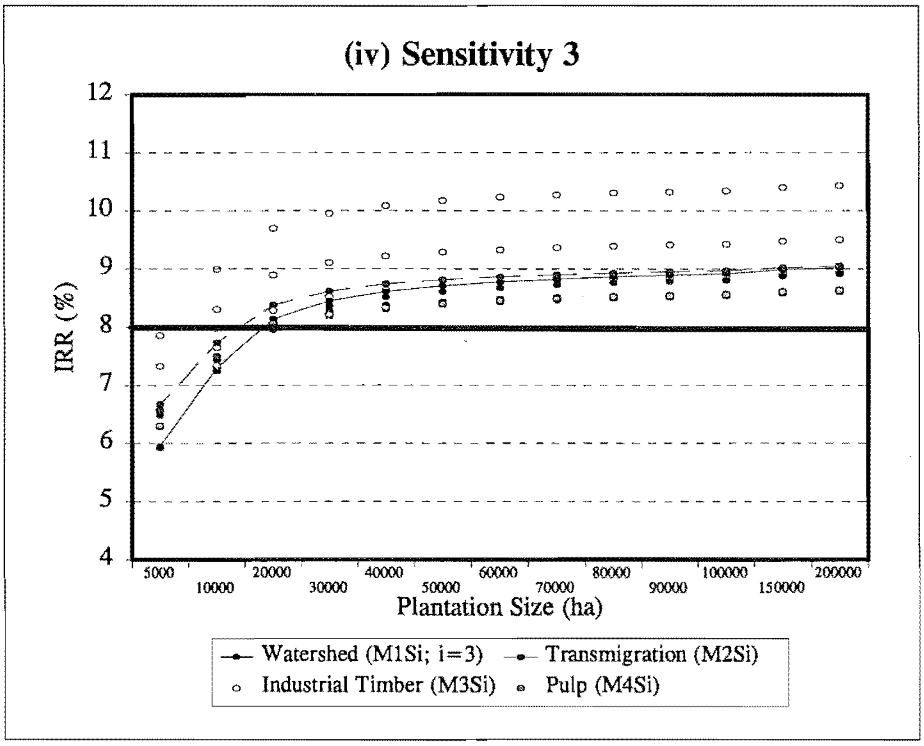
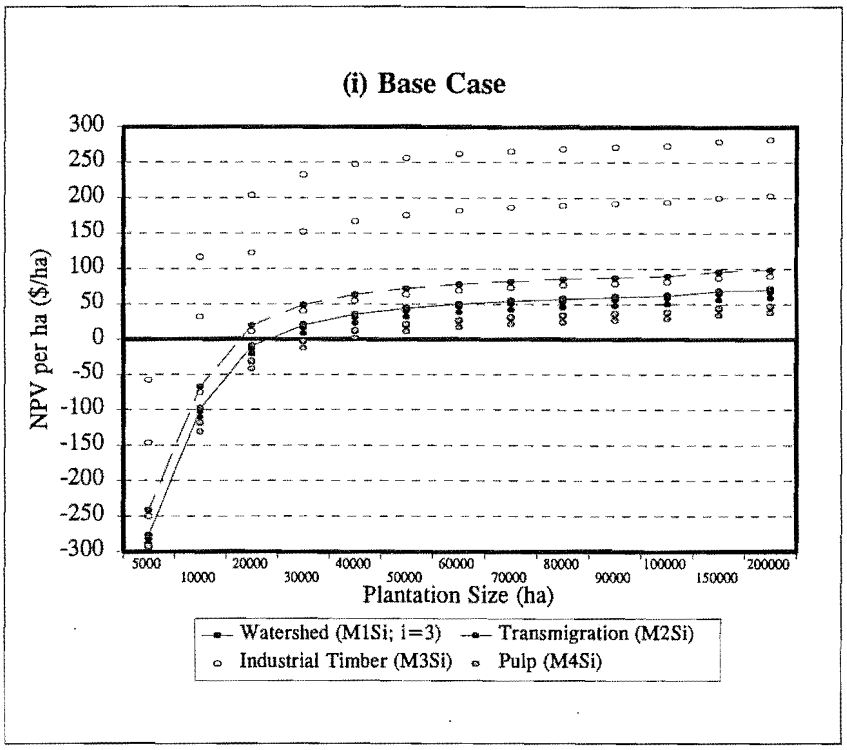


Figure 4.1.A. (continued)



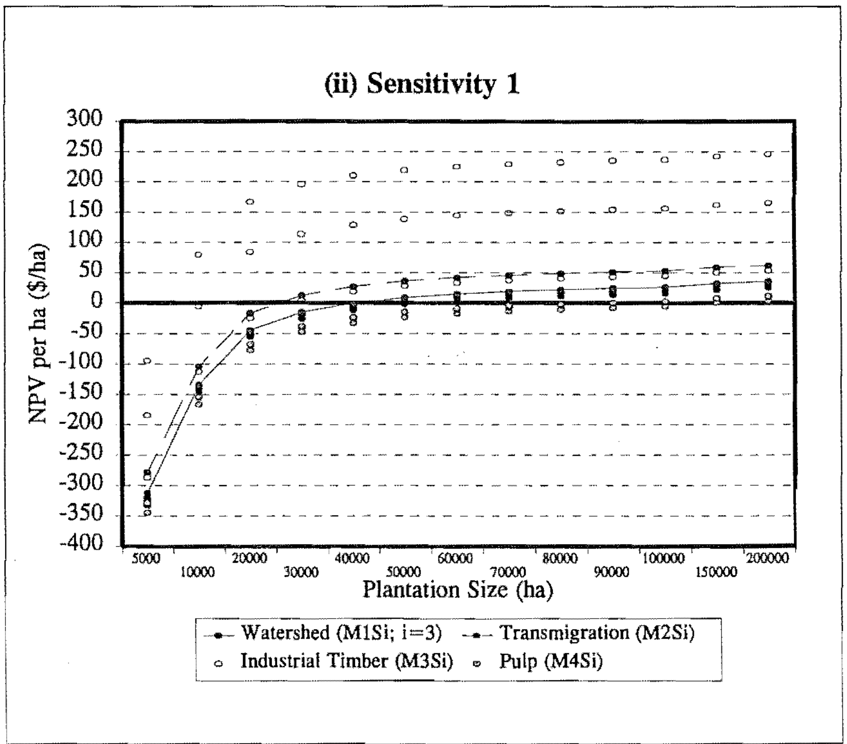
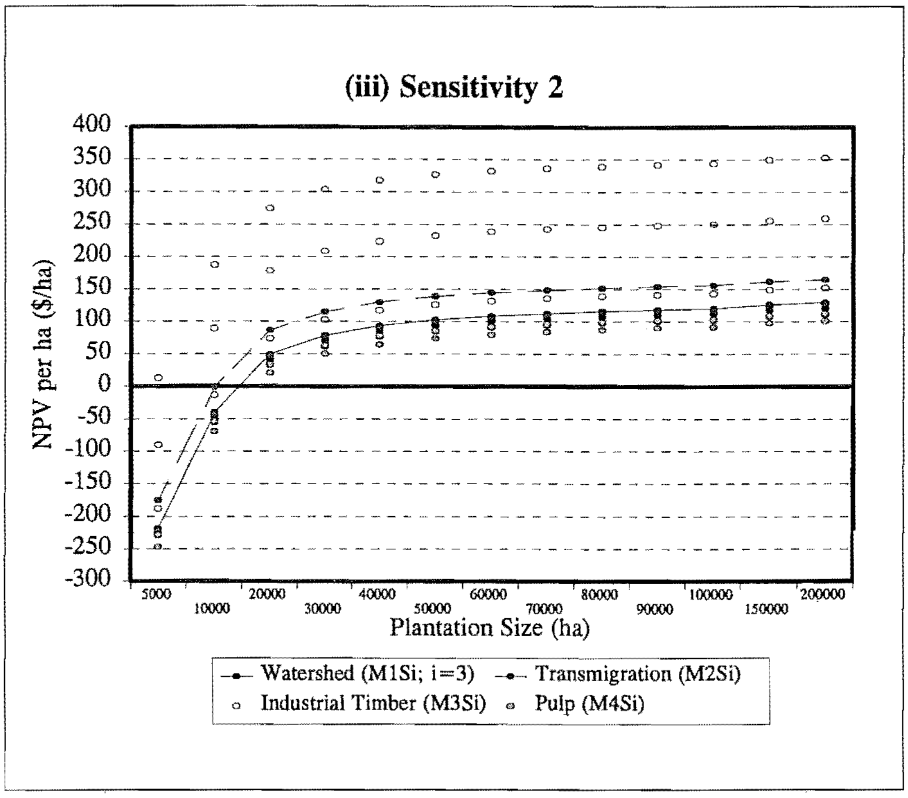


Figure 4.1.B. NPV per Hectare Comparison by different Plantation Size



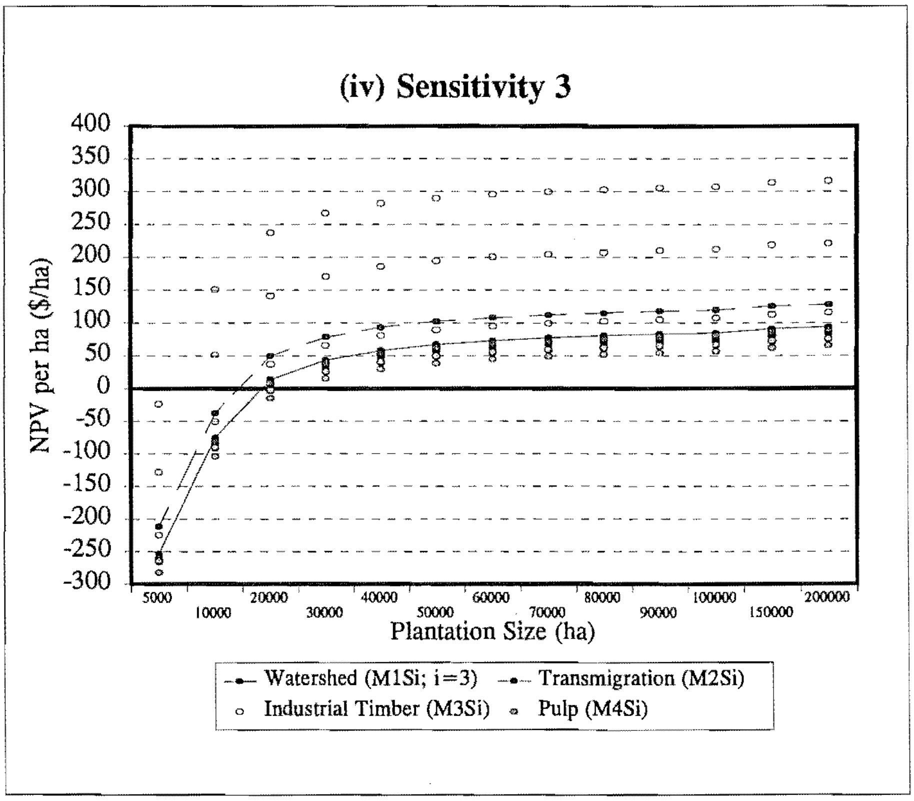
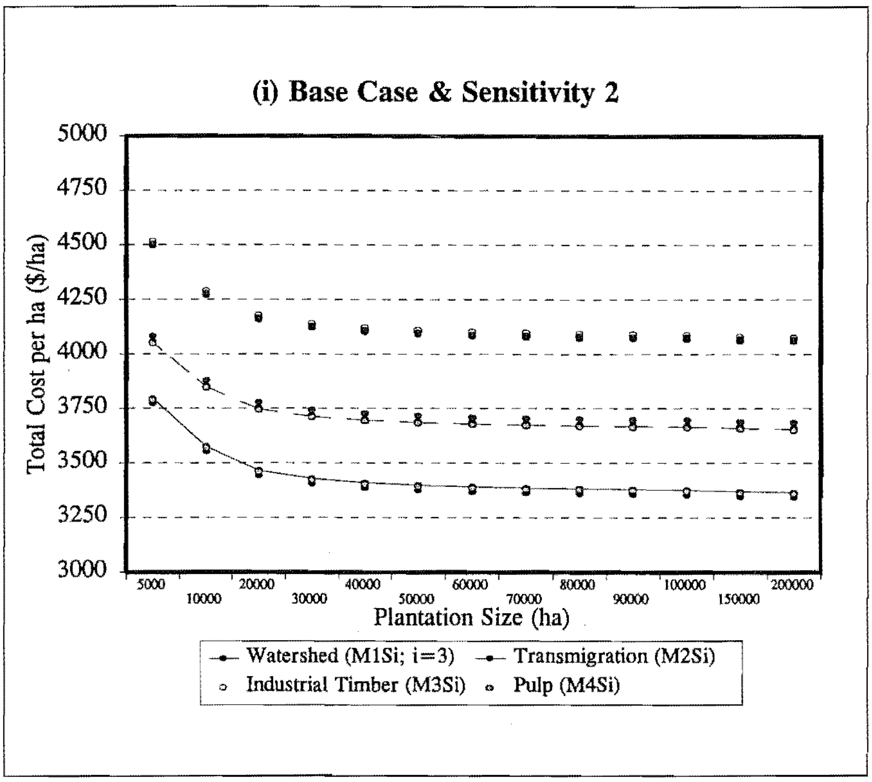


Figure 4.1.B. (continued)



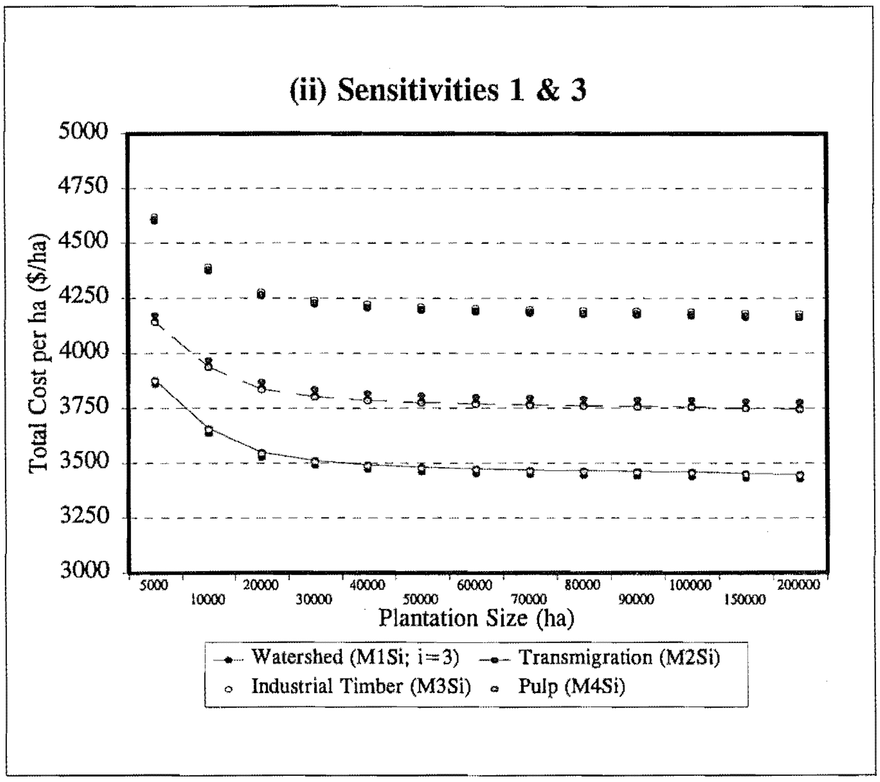


Figure 4.1.C Total Cost per Hectare Comparison by different Plantation Size

Figures 4.1.C.(i), 4.1.C.(ii), and Appendix 4.1.c shows a comparison of total cost per ha under base case, for example, that 5 000 ha and 10 000 ha give its total cost more than \$3,500 ha^{-1} for M_1S_1 option, i.e. \$3,795 ha^{-1}, and \$3,575 ha^{-1} respectively. Other plantation sizes yield less than \$3,500 ha^{-1}. Table 4.3 recapitulates the total cost per hectare for all plantation sizes. Appendices 4.1.c, 4.2.c, 4.3.c, and 4.4.c show the total cost per ha detail results.

Under base case and sensitivity 2 the difference between the lowest and the highest total cost per ha is \$1,176 ha^{-1} that is \$3,341 ha^{-1} for M_1S_2 and \$4,517 ha^{-1} for M_3S_3.

The highest total cost per ha is \$4,610 ha^{-1} (M_3S_3) and the lowest is \$3,424 ha^{-1} (M_1S_2) under the first and third sensitivities. The difference is \$1,186 ha^{-1}.

Figure 4.1 shows the IRRs for base case and those three sensitivities. An investment may be considered to be financially acceptable if its IRR is greater than the 8 per cent discount rate - the discount rate is calculated on an ad hoc, project to project basis and is determined during consideration of the loan (ADB, 1990; *pers. comm*) - for example (under sensitivity 1), starting from 10 000 ha plantation size (M_3S_2), 20 000 ha (M_3S_3), 30 000 ha (M_2S_1, M_2S_2, and M_3S_1), 40 000 ha (M_1S_1), 50 000 ha (M_1S_3 and M_2S_3), 60 000 ha (M_1S_2), 90 000 ha (M_4S_3), 100 000 ha (M_4S_2), and 150 000 ha (M_4S_1), their calculated IRRs show that investment in these management regimes acceptable (Table 4.5.a). Those IRRs (Table 4.5.a) are 8.5 per cent (for M_3S_2 and M_3S_3 respectively), 8.09 per cent, 8.1 per cent, and 8.03 per cent (M_2S_1, M_2S_2, and M_3S_1), 8.0 per cent (M_1S_1), 8.02 per cent and 8.06 per cent (M_1S_3 and M_2S_3), 8.04 per cent (M_1S_2), 8.01 per cent (M_4S_3), 8.01 per cent (M_4S_2), and 8.0 per cent (M_4S_1).

Their total costs per hectare (Table 4.5.c) are \$3,941 ha^{-1} (M_3S_2), \$4,280 ha^{-1} (M_3S_3), \$3,385 ha^{-1}, \$3,803 ha^{-1}, and \$3,808 ha^{-1} (for M_2S_1, M_2S_2, and M_3S_1 respectively), \$3,493 ha^{-1} (M_1S_1), \$4,190 ha^{-1} and \$4,201 ha^{-1} (M_1S_3 and M_2S_3), \$3,450 ha^{-1} (M_1S_2), \$3,754 ha^{-1} (M_4S_3), \$3,750 ha^{-1} (M_4S_2), and \$3,447 ha^{-1} (M_4S_1).

Table 4.3 recapitulates the minimum economic size for the various combination of management regimes and species. Base case results were utilised and attached to the forestland allocation model in the minimum area constraints for any given crop types.

4.5. **Forestland Allocation Model: results obtained**

The forestland allocation model shows firstly that when those six individual objective functions were run, the resulting objective function values obtained become goal targets or constraints in the MINMAX and MINSUM formulations. Three cases were utilised:

(i) without MES;
(ii) with MES, and;
(iii) with MES and lower and/or upper limits for non pulp and pulp log productions for any given location.

Table 4.4 provides forestland solution for various objective function weights.

Table 4.3. MES Ranges for Base Case and different Sensitivities

Management Regime	Species	Code	Base Case	Sensitivity 1	Sensitivity 2	Sensitivity 3
			Minimum Economic Size for IRR over 8% (ha)			
Watershed Part Protection Commercial WPPC	*Albizzia falcataria*	*M1S1*	30000	40000	20000	20000
	Calliandra calothyrsus	*M1S2*	30000	60000	20000	20000
	Dalbergia latifolia	*M1S3*	20000	50000	20000	20000
Hutan Tanaman Industri-Transmigrasi HTIT	*Albizzia falcataria*	*M2S1*	20000	30000	10000	20000
	Eucalyptus deglupta	*M2S2*	20000	30000	20000	20000
	Gmelia arborea	*M2S3*	30000	50000	20000	20000
Industrial Grade Timber IGT	*Eucalyptus deglupta*	*M3S1*	20000	30000	20000	20000
	Eucalyptus urophylla	*M3S2*	10000	10000	5000	10000
	Gmelia arborea	*M3S3*	10000	20000	10000	10000
Pulp Plantation PP	*Acacia mangium*	*M4S1*	40000	150000	20000	30000
	Eucalyptus deglupta	*M4S2*	40000	100000	20000	30000
	Eucalyptus urophylla	*M4S3*	40000	90000	20000	30000

Sensitivity 1: 3% Increase in Costs.
Sensitivity 2: 0.3% & 0.1% Increase in Non Pulp Log & Pulp Log Prices.
Sensitivity 3: 3% Increase in Costs, 0.3% Increase in Non Pulp Log Price & 0.1% Pulp Log Price.

Without MES, the six optimal solutions derived when optimising each objective function separately quite are different. The first and second objective solutions produce 109 million m^3 non pulp logs and 391 million m^3 of pulp logs. The third, fourth, and sixth objectives yield 18 480, 16 014, and 154 258 utils relating to maximising soil protection, subsistence for local community, and readiness plantation arrangement respectively. Finally, the fifth solution provides NZ$14,000 million in terms of revenue for the organisation.

The MINMAX formulation (with equal weight or all '1' in the weight structure) gave individual percent achievements for objectives 1, 2, 3, 4, and 6 (77.3 per cent), and objective 5 (86.3 per cent) whereas MINSUM formulation (with equal weight) gave objective 1 (72.9 per cent), objective 2 (79 per cent), objective 3 (69 per cent), objective 4 (79.4 per cent), objective 5 (90.2 per cent), and objective 6 (78.8 per cent). Table 4.4 shows these solutions.

With MES, the results follow a slightly different pattern. After the six single objective functions were run separately, the MINMAX and MINSUM formulations (equal weights) were set up and run. Optimal values for these single objective functions were lower than in the first case, due to introducing the MES values. For objective 1 (maximise non pulp log production) gave a lower values, i.e. 91 million $m^3 < 109$ million m^3 or approximately 16.5 per cent lower. The difference for objective 2 (maximise pulp production) was 16.8 per cent lower for case 2 (with MES) than base case. For objectives 3, 4, 5, and 6 their different values were 8 per cent, 7.2 per cent, 12.6 per cent, 8 per cent, and 13.3 per cent respectively. Those MES values as lower limit constraints play a major role in distributing the forestland allocation which can be depicted by its percent of achievement. Under MINMAX and MINSUM formulations, all percentage achievements of objectives were higher than in the first case (without MES). Table 4.5 shows the detailed model solutions.

With MES and lower and/or upper limits, all single functional values were lower than in the first and second cases. Their value differences were 20.7 per cent, 14.8 per cent, 11.8 per cent, 16.3 per cent, 8.8 per cent, 16.6 per cent lower than case 1 for the six objectives. All MINMAX and MINSUM formulations (equal weights) gave higher percentage achievements (Table 4.6).

The solutions alter depending on the weights applied and therefore provide logical and rational insights into the best compromise forestland allocations. Tables 4.4, 4.5, and 4.6 also show several extended different weight applications.

When objective 1 was given a weight of 10, and all others held at 1, then the same weight structure applied to each of the other objectives 2, 3, 4, 5 and 6, the results showed that those objectives weighted 10 gave the highest percent of achievements, i.e. 96.7 per cent, 97.5 per cent, and 98.4 per cent under MINMAX formulation and 83.2 per cent, 100 per cent, and 100 per cent under MINSUM formulation respectively for cases 1, 2, and 3. In addition, the higher percentage achievements for these three cases are expected because of their relative percent of achievements from their corresponding six new single optimal solutions (i.e. for sensitivity 2: with MES and sensitivity 3: with MES and U/L limits). Similar increasing percentage achievements for objectives 2, 3, 4, 5, and 6 under MINMAX and MINSUM formulations are obtained for all three cases.

Table 4.4. Forestland Solution for various Objective Weights: Case 1 (Base Case)

Formulation	Weight for Goal						*v and wi*vi* values	Functional Value & Percent Achievement for Goal					
	1	2	3	4	5	6		1	2	3	4	5	6
								(000 cum)		(util)		($000)	(util)
With MES & U/L limits: single	1	0	0	0	0	0	-	109495					
	0	1	0	0	0	0	-		391647				
	0	0	0	0	0	0	-			18480			
	0	0	0	1	0	0	-				16014		
	0	0	0	0	1	0	-					14878187	
	0	0	0	0	0	1	-						154258
								Percent of Achievement (%)					
MINMAX	1	1	1	1	1	1	v: 0.2270	77.3	77.3	77.3	77.3	86.3	77.3
	10	1	1	1	1	1	v: 0.3298	96.7	67.0	75.0	83.2	94.3	75.1
	1	10	1	1	1	1	v: 0.5624	43.8	94.4	56.9	88.8	79.6	74.6
	1	1	10	1	1	1	v: 0.4313	76.6	62.1	95.7	56.9	90.3	56.9
	1	1	1	10	1	1	v: 0.3043	69.6	69.6	69.6	97.0	81.2	87.1
	1	1	1	1	10	1	v: 0.2422	86.7	76.7	75.8	75.8	97.6	75.8
	1	1	1	1	1	10	v: 0.3541	64.6	64.6	64.6	73.5	76.5	96.5
MINSUM	1	1	1	1	1	1	wi*vi 0.059891	82.7	80.4	73.8	87.8	95.9	76.8
	10	1	1	1	1	1	wi*vi 0.149818	100.0	58.9	87.4	59.7	94.2	74.0
	1	10	1	1	1	1	wi*vi 0.149881	43.5	94.4	56.9	88.8	79.5	74.5
	1	1	10	1	1	1	wi*vi 0.149415	72.9	70.7	99.8	53.6	92.2	39.7
	1	1	1	10	1	1	wi*vi 0.149325	64.3	67.4	67.7	100.0	79.7	89.9
	1	1	1	1	10	1	wi*vi 0.149894	91.2	77.8	71.0	83.2	99.1	73.3
	1	1	1	1	1	10	wi*vi 0.149840	60.3	67.9	58.9	88.9	75.5	100.0

Notes: (i) summation of $w_i v_i = w_1v_1 + w_2v_2 + w_3v_3 + w_4v_4 + w_5v_5 + w_6v_6$.

(ii) U/L limits = Upper and/or Lower limits for non pulp log and pulp log production.

goal 1: maximise non pulp log production (cum)

goal 2: maximise pulp log production (cum)

goal 3: maximise soil protection (util)

goal 4: maximise subsistence for local community (util)

goal 5: maximise revenue for the organisation (NZ$)

goal 6: maximise the readiness of croptype development (util)

Table 4.5. Forestland Solution for various Objective Weights: Case 2 (with MES)

Formulation	Weight for Goal						v and wi*vi values	Functional Value & Percent Achievement for Goal					
	1	2	3	4	5	6		1	2	3	4	5	6
								(000 cum)		(util)		($000)	(util)
With MES & U/L limits: single	1	0	0	0	0	0	-	91067					
	0	1	0	0	0	0	-		360126				
	0	0	0	0	0	0	-			17149			
	0	0	0	1	0	0	-				13990		
	0	0	0	0	1	0	-					13682719	
	0	0	0	0	0	1	-						133734
								Percent of Achievement (%)					
MINMAX	1	1	1	1	1	1	v: 0.1834	81.7	81.7	81.7	81.7	91.8	81.7
	10	1	1	1	1	1	v: 0.2497	97.5	75.0	76.3	89.1	95.2	91.0
	1	10	1	1	1	1	v: 0.4658	53.4	95.3	72.6	91.9	86.3	73.9
	1	1	10	1	1	1	v: 0.4039	74.1	75.4	96.0	63.0	93.1	59.6
	1	1	1	10	1	1	v: 0.2401	76.0	76.0	80.4	97.6	89.0	86.2
	1	1	1	1	10	1	v: 0.1948	85.0	84.4	80.5	80.5	98.1	80.5
	1	1	1	1	1	10	v: 0.2447	75.5	75.5	75.5	88.5	85.2	97.6
MINSUM	1	1	1	1	1	1	wi*vi 0.059873	87.6	85.9	74.3	90.9	98.1	90.9
	10	1	1	1	1	1	wi*vi 0.149778	100.0	69.8	83.2	76.2	94.6	90.5
	1	10	1	1	1	1	wi*vi 0.000176	47.0	96.8	71.6	90.6	84.3	71.2
	1	1	10	1	1	1	wi*vi 0.149360	66.3	82.5	100.0	60.9	93.8	43.2
	1	1	1	10	1	1	wi*vi 0.149223	68.0	78.8	79.2	100.0	85.1	86.3
	1	1	1	1	10	1	wi*vi 0.149874	92.0	84.8	72.8	89.1	99.5	89.2
	1	1	1	1	1	10	wi*vi 0.149805	75.7	71.1	75.0	93.2	84.6	100.0

Notes: (i) summation of $w_i v_i = w_1v_1 + w_2v_2 + w_3v_3 + w_4v_4 + w_5v_5 + w_6v_6$.

(ii) U/L limits = Upper and/or Lower limits for non pulp log and pulp log production.

goal 1: maximise non pulp log production (cum)

goal 2: maximise pulp log production (cum)

goal 3: maximise soil protection (util)

goal 4: maximise subsistence for local community (util)

goal 5: maximise revenue for the organisation (NZ$)

goal 6: maximise the readiness of croptype development (util)

Table 4.6. Forestland Solution for various Objective Weights: Case 3 (with MES and U/L Limits)

Formulation	Weight for Goal 1	2	3	4	5	6	v and wi*vi values		Functional Value & Percent Achievement for Goal 1	2	3	4	5	6
									(000 cum)		(util)		($000)	(util)
With MES & U/L limits: single	1	0	0	0	0	0		-	86756					
	0	1	0	0	0	0		-		333329				
	0	0	0	0	0	0		-			16295			
	0	0	0	1	0	0		-				13397		
	0	0	0	0	1	0		-					13566849	
	0	0	0	0	0	1		-						128651
									Percent of Achievement (%)					
MINMAX	1	1	1	1	1	1	v:	0.1382	86.2	86.2	86.2	86.2	90.7	86.2
	10	1	1	1	1	1	v:	0.1593	98.4	84.1	84.1	84.1	97.7	92.5
	1	10	1	1	1	1	v:	0.2605	74.0	97.4	78.9	95.3	92.0	81.6
	1	1	10	1	1	1	v:	0.3274	79.1	84.0	96.7	73.2	93.1	67.3
	1	1	1	10	1	1	v:	0.1712	82.9	82.9	84.2	98.3	91.4	86.9
	1	1	1	1	10	1	v:	0.1529	90.0	90.3	84.7	84.7	98.5	84.7
	1	1	1	1	1	10	v:	0.1852	87.6	81.5	81.5	83.6	90.8	98.1
	5	5	1	1	1	1	v:	0.3877	92.2	92.2	77.6	92.5	97.6	90.9
	1	1	5	5	1	1	v:	0.4917	77.1	86.1	90.2	90.2	92.3	72.1
	1	1	1	1	5	5	v:	0.1369	97.9	82.3	81.8	82.3	96.4	96.4
	2	2	1	1	1	1	v:	0.1799	91.0	91.0	82.0	87.7	98.0	89.7
	1	1	2	2	1	1	v:	0.1799	79.8	83.2	89.7	89.7	91.8	79.4
	1	1	1	1	2	2	v:	0.1546	86.7	84.5	84.5	84.5	92.3	92.3
MINSUM	1	1	1	1	1	1	wi*vi:	0.059862	95.7	90.5	78.5	91.6	99.5	93.3
	10	1	1	1	1	1	wi*vi:	0.149760	100.0	82.5	83.9	84.7	97.2	93.9
	1	10	1	1	1	1	wi*vi:	0.149839	63.9	99.8	77.3	93.4	88.9	77.4
	1	1	10	1	1	1	wi*vi:	0.149318	77.1	87.0	100.0	69.7	94.8	57.3
	1	1	1	10	1	1	wi*vi:	0.149184	76.7	85.7	82.9	100.0	88.2	87.6
	1	1	1	1	10	1	wi*vi:	0.149862	95.9	90.5	78.5	91.6	99.6	93.3
	1	1	1	1	1	10	wi*vi:	0.149795	87.1	82.9	76.8	91.0	90.9	100.0

Notes: (i) summation of $wi\ vi = w1v1 + w2v2 + w3v3 + w4v4 + w5v5 + w6v6$.

(ii) U/L limits = Upper and/or Lower limits for non pulp log and pulp log production.

Further different weights such as 5 and 2 were applied to case 3 (with MES and U/L limits). For example, combined objectives 1 (max non pulp log production) and 2 (max pulp log production), under "5" weight gave 92.2 per cent of achievement and under "2" weight, gave 91 per cent, which represents differences of approximately 1.04 million m^3 non pulp log and nearly 4 million m^3 pulp log in production. For objectives 3 (max soil protection) and 4 (max subsistence for local community) the combination of 90.2 per cent was achieved each under weight "5" and 89.7 per cent under weight "2". Discrepancies were approximately 81 utils and 66 utils for objectives 3 and 4 respectively. The combined last two objectives, i.e. 5 (max revenue for organisation) and 6 (max the readiness of the plantation arrangement) gave percentage achievements of 96.4 per cent under weight "5" and 92.3 per cent under weight "2" (Table 4.6). Differences were just over a half million dollars and 5 274 utils respectively.

In the MINMAX formulation, variable v was introduced and utilised to measure minimisation of the maximum deviation of any goal achievement from the ideal. Wider weight structures were able to screen various variable v values. For example, in Case 3 (with MES and U/L limits in Table 4.6), the combination of objectives 5 (max revenue) and 6 (max the readiness) with their weight structures of "5" and the rest of other objectives of weight of "1", gave variable v of 0.1369 which was slightly lower than if all objectives were given equal "1" weight, i.e. 0.1382. This has significant implications on the individual objective function values. All objective function values increase, except for objectives 3 and 4. In other words, by emphasising objectives 5 and 6, a fair balance of several better objectives and sacrifices in the other objectives appears to have been obtained.

The MINSUM formulation shows that a minor change in weights may cause the optimal solution to change to an adjacent extreme point of the feasible solution. For example, in Case 3 (Table 4.6), while single objectives 1, 2, 3, 4, 5, and 6 were weighted single "10" and other objectives were weighted single "1", percentage achievements for objectives 1, 3, 4, and 6 were 100 per cent which represent the maximum possible. Objectives 2 and 5 were 99.8 per cent and 99.6 per cent respectively which were closer to their own extreme points as well. In MINSUM formulation, variables $w_i v_i$ were used to minimised the weighted sum of this sum fractional deviations from the targets. For equal weights of "1" for all objectives, the summing up of $w_i v_i$ was 0.0598 (Table 4.6).

This formulation gave a fair balance among objectives 1 (percentage achievement of 95.7 per cent), 2 (90.5 per cent), 4 (91.6 per cent), 5 (99.5 per cent), and 6 (93.3 per cent), but not for objective 3 (78.5 per cent). Among the MINSUM formulations with weight "10" applied to every single objective, the next lower value for $w_i v_i$ was 0.149184 (weight "10" is applied for objective 4 and the other objectives are weight "1"). This formulation gave percentage achievements for objectives 1 (76.7 per cent), 2 (85.7 per cent), 3 (82.9 per cent), 4 (100 per cent), 5 (88.2 per cent), and 6 (87.6 per cent).

These MINSUM formulation examples (Table 4.6) performed contrary to what might be reasonably expected. As Table 4.6 summarises the response of the optimal solution to various weight combinations (w_i), the theoretical hint such as the negative of the constraint slope was applicable in up to two objectives with limited number of constraints (Daellenbach et al., 1983) and it was ineffective or impractical for models with more than two objectives and significant numbers of constraints in the real world problems due to the multi-dimensional magnitude of the problem. Minor changes in MINSUM formulation weights may cause optimal solutions to change quite suddenly to a neighbouring extreme point of feasible region. On the other hand, a feature of the MINMAX formulation is that the optimal solution responds gradually and smoothly to changes of weights. If DMs would desire the optimal solution to respond gradually to iterative changes in the weight structure, I consider MINMAX formulation to give a more equitable distribution to the percentage of goal achievements than the MINSUM formulation. Both formulations provide major advantages such as simplicity and a conversion from MODM problems to conventional LP.

Tables 4.7, 4.8, 4.9, 4.10 present forestland allocation solutions by management regime for cases 1 (without MES), 2 (with MES), and 3 (with MES and lower and/or upper limits).

The first case allocates for example under MINMAX formulation (equal weight) for location 1 under management regime 1, M_1 (200 000 ha), M_3 (365 000 ha), and none for M_4. For location 2, M_1 (300 000 ha), M_2 (57 000 ha), M_3 (320 000 ha), and none for M_4. For the third, fourth and fifth locations, M_1 (3 000 ha)and M_3 (275 000 ha); M_1 (305 ha), M_2 (15 000 ha); and M_1 (290 000 ha). Table 4.7 shows other details for objectives 2, 3, 4, 5, 6, under MINMAX and MINSUM (equal weight) formulations.

For the second case, those lower forestland allocations were re-allocated, i.e. for location 1, M_4 (120 000 ha from 0 ha); location 2, M_1 (167 000 ha from 300 000 ha) and M_2 (70 000 ha from 57 000 ha), M_4 (120 000 ha from 0 ha); location 3, M_1 (80 000 ha from 3 000 ha) and M_3 (198 000 ha from 275 000 ha); location 4, M_1 (250 000 ha from 305 000 ha) and M_2 (70 000 ha from 15 000 ha). The other allocations vary from 70 000 ha to 365 000 ha. Table 4.8 shows other forestland allocation details.

The third case distributes a slightly different forestland allocation for all locations and management regimes, for:

1. objective 1, location 2 (M_1: 80 000 ha, M_2: 190 000 ha, and M_3: 287 000 ha);
2. objective 2, location 1 (M_1: 80 000 ha, M_3: 275 000 ha and M_4: 210 000 ha), location 3 (M_1: 80 000 ha and M_3: 198 000 ha), location 4 (M_1: 119 000 ha and M_2: 201 000 ha);
3. objective 3, location 1 (M_1: 287 000 ha, M_3: 158 000 and M_4: 120 000 ha), location 3 (M_1: 92 000 ha and M_3: 186 000 ha);
4. objective 4, location 4 (M_1: 119 000 ha and M_2: 201 000 ha);
5. objective 5, location 2 (M_1: 80 000 ha, M_2: 190 000 ha, M_3: 287 000 ha);
6. objective 6, location 4 (M_1: 119 000 ha and M_2: 201 000 ha), and;
7. MINMAX (equal formulation), location 1 (M_1: 80 000 ha, M_3: 365 000 ha),

location 2 (M_1: 159 000 ha, M_2: 201 000 ha and M_4: 197 000 ha), location 3 (M_1: 88 000 ha and M_3: 190 000 ha); location 4 (M_1: 224 000 ha and M_2: 96 000 ha; and

8. MINSUM formulation (equal weight), location 4 (M_1: 119 000 ha and M_2: 201 000 ha).

Tables 4.9 and 4.10 show forestland allocation solutions by management regime under case 3 for various combinations of the weight structures in MINMAX and MINSUM formulations, i.e. weights "5" and "2".

Tables 4.11, 4.12 and 4.13 provide model solutions with single objective optimisation, MINMAX and MINSUM formulations for managing forestland with case 1 (without MES), case 2 (with MES), and case 3 (with MES and lower and/or upper limits).

For case 1 objective 1 (maximise non pulp log production), the forestland allocated in location 1 were for M_1 (D. latifolia: 200 000 ha) and M_2 (E. urophylla: 360 000 ha and G. arborea: 5 000 ha); location 2 for M_1 (D. latifolia: 300 000 ha), M_2 (G. arborea: 57 000 ha); M_3 (E. urophylla: 300 00 ha and G. arborea: 20 000 ha); location 3 for M_1 (D.latifolia: 3 000 ha), M_3 (E. urophylla: 275 000 ha); location 4 for M_1 (D. latifolia: 305 000 ha) and M_2 (G. Arborea: 15 000 ha); location 5 for M_2 (A. falcataria: 35 000 ha and G. Arborea: 255 000 ha). The other single models and MINMAX and MINSUM formulations were shown by Table 4.9.

The second and third cases, the compromise solutions gave different forestland allocations in terms of locations, management regimes, and species. All crop types were included and all these runs give the opportunity to explore technical options.

Tables 4.14, 4.15, and 4.16 present the forestland allocation solution by different species. These species distributions and requirements during the implementation of industrial forest plantation development provide important information in order to balance, for example, species composition, seed quantity and quality, and immediate local preferences or needs.

In case 1 (without MES) objective 1 (max non pulp log production), forestland allocation was dominated by three species, i.e. E. urophylla (935 000 ha or nearly 44 per cent of the total forestland), D. latifolia (808 000 ha or 40 per cent), and G. arborea (352 000 ha or 16.5 per cent); A. falcataria was allocated for 35 000 ha (1.6 per cent) while the other species were not selected, i.e. A. mangium, C. calothyrsus, and E. deglupta).

Model solutions for objective 2 (max pulp log production) emphasise different main species, i.e. A. mangium (670 000 ha or 31.4 per cent), A. falcataria (590 000 ha or 27.6 per cent), and C. calothyrsus (552 000 ha or 25.9 per cent) while for objective 3 (max soil protection) yield D. latifolia (1 155 000 ha or 54.2 per cent) as the primary species. E. deglupta was the main species in objective 4 (max subsistence for local community: 1 240 000 ha or 58.2 per cent) whereas G. arborea (1 242 000 ha or 58.3 per cent) was the major species contributing to maximise revenue for the organisation (objective 5).

Table 4.7. Forestland Allocation Solution by Management Regime: Case 1 (Base Case)

Location	Management Regime	Forestland Allocation for Objective (000 ha)							
		1	2	3	4	5	6	MINMAX equal	MINSUM equal
1	*M1*	200	215	305	0	235	0	200	200
	M3	365	0	260	365	330	365	365	365
	M4	0	350	0	200	0	200	0	0
	Sub Total	565	565	565	565	565	565	565	565
2	*M1*	300	77	300	0	300	0	300	47
	M2	57	280	310	310	57	12	48	310
	M3	320	0	67	320	320	320	320	320
	M4	0	320	0	47	0	345	9	0
	Sub Total	677	677	677	677	677	677	677	677
3	*M1*	3	250	250	3	3	3	3	3
	M3	275	28	28	275	275	275	275	275
	Sub Total	278	278	278	278	278	278	278	278
4	*M1*	305	10	305	5	305	10	35	5
	M2	15	310	15	315	15	310	285	315
	Sub Total	320	320	320	320	320	320	320	320
5	*M1*	290	290	290	290	290	290	290	290
	Sub Total	290	290	290	290	290	290	290	290
	Total	2130	2130	2130	2130	2130	2130	2130	2130

Table 4.8. Forestland Allocation Solution by Management Regime: Case 2 (with MES)

Location	Management Regime	Forestland Allocation for Objective (000 ha)							
		1	2	3	4	5	6	MINMAX equal	MINSUM equal
1	*M1*	80	175	305	80	85	80	123	80
	M3	365	40	140	365	360	365	322	365
	M4	120	350	120	120	120	120	120	120
	Sub Total	565	565	565	565	565	565	565	565
2	*M1*	167	80	300	80	167	80	167	80
	M2	70	212	217	310	70	70	70	157
	M3	320	40	40	167	320	320	320	320
	M4	120	345	120	120	120	207	120	120
	Sub Total	677	677	677	677	677	677	677	677
3	*M1*	80	238	238	80	80	80	177	80
	M3	198	40	40	198	198	198	101	198
	Sub Total	278	278	278	278	278	278	278	278
4	*M1*	250	80	250	80	250	80	96	80
	M2	70	240	70	240	70	240	224	240
	Sub Total	320	320	320	320	320	320	320	320
5	*M1*	290	290	290	290	290	290	290	290
	Sub Total	290	290	290	290	290	290	290	290
	Total	2130	2130	2130	2130	2130	2130	2130	2130

Table 4.9. Forestland Allocation Solution by Management Regime: Case 3 (with MES & U/L Limits)

Location	Management Regime	Forestland Allocation for Objective (000 ha)							
		1	2	3	4	5	6	MINMAX equal	MINSUM equal
1	*M1*	80	80	287	80	85	80	80	80
	M3	365	275	158	365	360	365	365	365
	M4	120	210	120	120	120	120	120	120
	Sub Total	565	565	565	565	565	565	565	565
2	*M1*	80	80	300	80	80	80	159	80
	M2	190	212	217	310	190	70	201	157
	M3	287	40	40	167	287	320	197	320
	M4	120	345	120	120	120	207	120	120
	Sub Total	677	677	677	677	677	677	677	677
3	*M1*	80	80	92	80	80	80	88	80
	M3	198	198	186	198	198	198	190	198
	Sub Total	278	278	278	278	278	278	278	278
4	*M1*	250	119	250	119	250	119	224	119
	M2	70	201	70	201	70	201	96	201
	Sub Total	320	320	320	320	320	320	320	320
5	*M1*	290	290	290	290	290	290	290	290
	Sub Total	290	290	290	290	290	290	290	290
	Total	2130	2130	2130	2130	2130	2130	2130	2130

Table 4.10. Forestland Allocation Solution by Management Regime: Case 3 (with MES & U/L Limits) - continued

Location	Management Regime	Forestland Allocation for Objective (000 ha)																	
		1\	2\	3\	4\	5\	6\	1 & 2\	3 & 4\	5 & 6\	1 & 2\	3 & 4\	5 & 6\	1/	2/	3/	4/	5/	6/
		x '10' weight						x '5' weight			x '2' weight			x '10' weight					
1	*M1*	96	80	214	80	85	80	80	214	80	85	148	80	80	80	305	80	80	4
	M3	349	279	231	365	360	365	365	231	365	360	297	365	365	135	140	365	365	365
	M4	120	206	120	120	120	120	120	120	120	120	120	120	120	350	120	120	120	196
	Sub Total	565	565	565	565	565	565	565	565	565	565	565	565	565	565	565	565	565	565
2	*M1*	82	80	300	80	147	119	80	121	80	80	93	193	167	80	300	80	80	37
	M2	155	310	166	310	206	70	190	310	82	208	310	84	70	310	217	310	157	0
	M3	320	167	91	167	204	320	287	126	320	269	154	280	320	40	40	167	320	320
	M4	120	120	120	120	120	168	120	120	195	120	120	120	120	247	120	120	120	320
	Sub Total	677	677	677	677	677	677	677	677	677	677	677	677	677	677	677	677	677	677
3	*M1*	80	80	92	80	80	80	80	92	80	80	92	80	80	80	238	80	80	3
	M3	198	198	186	198	198	198	198	186	198	198	186	198	198	198	40	198	198	275
	Sub Total	278	278	278	278	278	278	278	278	278	278	278	278	278	278	278	278	278	278
4	*M1*	250	119	250	119	224	250	119	119	250	224	211	224	250	80	250	80	80	305
	M2	70	201	70	201	96	70	201	201	70	96	109	96	70	240	70	240	240	15
	Sub Total	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320
5	*M1*	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290
	Sub Total	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290	290
	Total	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130

Notes: (a). 1\, 2\, 3\, . . . , 3 & 4\, 5 & 6\ were MINMAX formulations.

(b). 1/, 2/, . . . , 6/ were MINSUM formulations.

Table 4.11. Model Solutions with MINMAX and MINSUM Formulations for Managing Forestland: Case 1 (Base Case)

Location	Management Regime (code)	Species	Variable	Forestland Allocation for Objective (000 ha)																			
				1	2	3	4	5	6	MINMAX	MINSUM	1\	2\	3\	4\	5\	6\	1/	2/	3/	4/	5/	6/
										equal	equal	x '10' weight						x '10' weight					
1	Watershed Part Protection Commercial WPPC (M1)	*Albizzia falcataria*	L1M1S1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Calliandra calothyrsus	L1M1S2	0	215	5	0	0	0	200	0	0	0	0	11	0	4	0	0	5	0	0	0
		Dalbergia latifolia	L1M1S3	200	0	300	0	235	0	0	200	200	0	257	0	200	0	200	0	300	0	200	0
	Industrial Grade Timber IGT (M3)	*Eucalyptus deglupta*	L1M3S1	0	0	260	335	0	335	0	0	0	0	308	41	0	335	0	0	0	335	0	335
		Eucalyptus urophylla	L1M3S2	360	0	0	30	0	30	35	35	360	0	0	324	35	30	360	0	260	0	35	30
		Gmelia arborea	L1M3S3	5	0	0	0	330	0	330	330	5	219	0	0	330	0	5	215	0	30	330	0
	Pulp Plantation PP (M4)	*Acacia mangium*	L1M4S1	0	350	0	200	0	200	0	0	0	346	0	0	0	196	0	350	0	0	0	200
		Eucalyptus deglupta	L1M4S2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Eucalyptus urophylla	L1M4S3	0	0	0	0	0	0	0	0	0	0	0	189	0	0	0	0	0	200	0	0
2	Watershed Part Protection Commercial WPPC (M1)	*Albizzia falcataria*	L2M1S1	0	0	0	0	0	0	0	0	0	0	0	0	0	37	0	0	0	0	0	0
		Calliandra calothyrsus	L2M1S2	0	77	0	0	0	0	300	0	0	0	0	47	0	0	0	0	0	0	0	0
		Dalbergia latifolia	L2M1S3	300	0	300	0	300	0	0	47	57	0	300	0	219	0	300	0	300	0	57	0
	Hutan Tanaman Industri-Transmigrasi HTIT (M2)	*Albizzia falcataria*	L2M2S1	0	280	280	280	0	12	48	280	0	280	67	280	0	0	0	280	280	280	0	12
		Eucalyptus deglupta	L2M2S2	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0
		Gmelia arborea	L2M2S3	57	0	30	0	57	0	0	30	300	30	0	30	92	0	57	30	0	0	300	0
	Industrial Grade Timber IGT (M3)	*Eucalyptus deglupta*	L2M3S1	0	0	67	310	0	310	0	0	0	0	310	268	0	310	0	0	0	310	0	310
		Eucalyptus urophylla	L2M3S2	300	0	0	10	10	10	133	10	300	0	0	0	10	10	300	0	97	0	10	10
		Gmelia arborea	L2M3S3	20	0	0	0	310	0	187	310	20	47	0	52	310	0	20	47	0	10	310	0
	Pulp Plantation PP (M4)	*Acacia mangium*	L2M4S1	0	320	0	47	0	320	9	0	0	320	0	0	0	320	0	320	0	0	0	320
		Eucalyptus deglupta	L2M4S2	0	0	0	0	0	25	0	0	0	0	0	0	45	0	0	0	0	0	0	25
		Eucalyptus urophylla	L2M4S3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47	0	0
3	Watershed Part Protection Commercial WPPC (M1)	*Albizzia falcataria*	L3M1S1	0	0	0	0	0	3	0	0	0	0	0	0	0	3	0	0	0	0	0	3
		Calliandra calothyrsus	L3M1S2	0	250	0	3	0	0	3	0	0	3	0	3	0	0	0	3	0	3	0	0
		Dalbergia latifolia	L3M1S3	3	0	250	0	3	0	0	3	3	0	250	0	3	0	3	0	250	0	3	0
	Industrial Grade Timber IGT (M3)	*Eucalyptus deglupta*	L3M3S1	0	0	28	270	0	270	0	0	0	0	28	270	0	270	0	0	0	270	0	270
		Eucalyptus urophylla	L3M3S2	275	0	0	5	0	5	275	0	111	0	0	0	0	5	275	0	28	0	0	5
		Gmelia arborea	L3M3S3	0	28	0	0	275	0	0	275	164	275	0	5	275	0	0	275	0	5	275	0
4	Watershed Part Protection Commercial WPPC (M1)	*Albizzia falcataria*	L4M1S1	0	0	0	0	0	10	0	0	0	0	0	0	0	181	0	0	0	0	0	5
		Calliandra calothyrsus	L4M1S2	0	10	0	5	0	0	35	0	0	5	0	5	0	124	0	5	0	5	0	0
		Dalbergia latifolia	L4M1S3	305	0	305	0	305	0	0	5	15	0	270	0	33	0	305	0	305	0	15	0
	Hutan Tanaman Industri-Transmigrasi HTIT (M2)	*Albizzia falcataria*	L4M2S1	0	310	15	310	0	310	285	310	0	310	50	310	287	15	0	310	15	310	0	310
		Eucalyptus deglupta	L4M2S2	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	5
		Gmelia arborea	L4M2S3	15	0	0	0	15	0	0	5	305	5	0	5	0	0	15	5	0	0	305	0
5	Hutan Tanaman Industri-Transmigrasi HTIT (M2)	*Albizzia falcataria*	L5M1S1	35	0	0	0	35	275	0	0	0	0	0	0	35	42	35	0	0	0	0	275
		Eucalyptus deglupta	L5M1S2	0	290	35	290	0	15	90	35	35	290	35	290	0	0	0	290	35	290	35	15
		Gmelia arborea	L5M1S3	255	0	255	0	255	0	200	255	255	0	255	0	255	248	255	0	255	0	255	0
			Total	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130

Notes: (a). 1\, 2\, 3\, . . . , 3 & 4\, 5 & 6\ were MINMAX formulations.
(b). 1/, 2/, . . . , 6/ were MINSUM formulations.

Table 4.12. Model Solutions with MINMAX and MINSUM Formulations for Managing Forestland: Case 2 (with MES)

Location	Management Regime (code)	Species	Variable	Forestland Allocation for Objective (000 ha)																			
				1	2	3	4	5	6	MINMAX	MINSUM	1\	2\	3\	4\	5\	6\	1/	2/	3/	4/	5/	6/
										equal	equal	x '10' weight						x '10' weight					
1	Watershed Part Protection Commercial WPPC (M1)	*Albizzia falcataria*	L1M1S1	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
		Calliandra calothyrsus	L1M1S2	30	125	30	30	30	30	73	30	30	30	30	30	30	30	30	30	30	30	30	30
		Dalbergia latifolia	L1M1S3	20	20	245	20	25	20	20	20	20	20	245	20	25	20	20	20	245	20	20	20
	Industrial Grade Timber IGT (M3)	*Eucalyptus deglupta*	L1M3S1	20	20	120	335	20	335	20	20	20	20	120	335	20	235	20	20	20	335	20	335
		Eucalyptus urophylla	L1M3S2	335	10	10	20	10	20	10	15	335	10	10	20	10	10	335	10	110	10	15	20
		Gmelia arborea	L1M3S3	10	10	10	10	330	10	292	330	10	192	10	10	330	120	10	105	10	20	330	10
	Pulp Plantation PP (M4)	*Acacia mangium*	L1M4S1	40	270	40	40	40	40	40	40	40	183	40	40	40	40	40	270	40	40	40	40
		Eucalyptus deglupta	L1M4S2	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
		Eucalyptus urophylla	L1M4S3	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
2	Watershed Part Protection Commercial WPPC (M1)	*Albizzia falcataria*	L2M1S1	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
		Calliandra calothyrsus	L2M1S2	30	30	30	30	30	30	117	30	30	30	30	30	30	30	30	30	30	30	30	30
		Dalbergia latifolia	L2M1S3	107	20	240	20	107	20	20	20	20	20	160	20	92	20	107	20	240	20	20	20
	Hutan Tanaman Industri-Transmigrasi HTIT (M2)	*Albizzia falcataria*	L2M2S1	20	162	167	260	20	20	20	107	20	260	20	247	20	20	20	260	167	260	20	20
		Eucalyptus deglupta	L2M2S2	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
		Gmelia arborea	L2M2S3	30	30	30	30	30	30	30	30	117	30	30	30	45	30	30	30	30	30	117	30
	Industrial Grade Timber IGT (M3)	*Eucalyptus deglupta*	L2M3S1	20	20	20	147	20	300	20	20	20	20	247	160	20	251	20	20	20	147	20	300
		Eucalyptus urophylla	L2M3S2	290	10	10	10	10	10	290	10	136	10	10	10	10	59	290	10	10	10	10	10
		Gmelia arborea	L2M3S3	10	10	10	10	290	10	10	290	164	10	10	10	290	10	10	10	10	10	290	10
	Pulp Plantation PP (M4)	*Acacia mangium*	L2M4S1	40	265	40	40	40	127	40	40	40	167	40	40	40	127	40	167	40	40	40	127
		Eucalyptus deglupta	L2M4S2	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
		Eucalyptus urophylla	L2M4S3	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
3	Watershed Part Protection Commercial WPPC (M1)	*Albizzia falcataria*	L3M1S1	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
		Calliandra calathyrsus	L3M1S2	30	188	30	30	30	30	114	30	30	30	30	30	30	30	30	30	30	30	30	30
		Dalbergia latifolia	L3M1S3	20	20	178	20	20	20	34	20	20	20	178	20	146	20	20	20	178	20	20	20
	Industrial Grade Timber IGT (M3)	*Eucalyptus deglupta*	L3M3S1	20	20	20	178	20	178	20	20	20	20	20	78	20	178	20	20	20	178	20	178
		Eucalyptus urophylla	L3M3S2	168	10	10	10	10	10	71	10	168	10	10	110	10	10	168	10	10	10	10	10
		Gmelia arborea	L3M3S3	10	10	10	10	168	10	10	168	10	168	10	10	42	10	10	168	10	10	168	10
4	Watershed Part Protection Commercial WPPC (M1)	*Albizzia falcataria*	L4M1S1	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
		Calliandra colathyrsus	L4M1S2	30	30	30	30	30	30	46	30	30	30	30	30	30	132	30	30	30	30	30	30
		Dalbergia latifolia	L4M1S3	190	20	190	20	190	20	20	20	20	20	190	20	46	20	190	20	190	20	20	20
	Hutan Tanaman Industri-Transmigrasi HTIT (M2)	*Albizzia falcataria*	L4M2S1	20	190	20	20	20	190	174	190	20	190	20	190	164	88	20	190	20	190	20	190
		Eucalyptus deglupta	L4M2S2	20	20	20	190	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
		Gmelia arbarea	L4M2S3	30	30	30	30	30	30	30	30	200	30	30	30	30	30	30	30	30	30	200	30
5	Hutan Tanaman Industri-Transmigrasi HTIT (M2)	*Albizzia falcataria*	L5M1S1	30	30	30	30	30	240	30	30	30	30	30	30	30	30	30	30	30	30	30	240
		Eucalyptus deglupta	L5M1S2	30	240	30	240	30	30	30	30	30	240	30	30	30	240	30	240	30	240	30	30
		Gmelia arborea	L5M1S3	230	20	230	20	230	20	230	230	230	20	230	230	230	20	230	20	230	20	230	20
			Total	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130

Notes: (a). 1\, 2\, 3\, . . . , 3 & 4\, 5 & 6\ were MINMAX formulations.
(b). 1/, 2/, . . . , 6/ were MINSUM formulations.

Table 4.13. Model Solutions with MINMAX and MINSUM Formulations for Managing Forestland: Case 3 (with MES & Upper/Lower Limits)

Location	Management Regime (code)	Species	Variable	Forestland Allocation for Objective (000 ha)																					
				1	2	3	4	5	6	MINMAX equal	MINSUM equal	1\	2\	3\	4\	5\	6\	1/	2/	3/	4/	5/	6/
												x '10' weight						x '10' weight					
1	Watershed Part Protection Commercial WPPC (M1)	*Albizzia falcataria*	L1M1S1	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
		Calliandra calothyrsus	L1M1S2	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
		Dalbergia latifolia	L1M1S3	20	20	227	20	25	20	20	20	36	20	154	20	25	20	20	20	227	20	20	20
	Industrial Grade Timber IGT (M3)	*Eucalyptus deglupta*	L1M3S1	20	20	20	335	20	335	20	20	20	20	211	335	20	335	20	20	20	335	20	335
		Eucalyptus urophylla	L1M3S2	335	10	128	20	10	20	294	15	296	10	10	20	10	20	335	10	128	10	15	20
		Gmelia arborea	L1M3S3	10	245	10	10	330	10	51	330	33	249	10	10	330	10	10	245	10	20	330	10
	Pulp Plantation PP (M4)	*Acacia mangium*	L1M4S1	40	130	40	40	40	40	40	40	40	126	40	40	40	40	40	130	40	40	40	40
		Eucalyptus deglupta	L1M4S2	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
		Eucalyptus urophylla	L1M4S3	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
2	Watershed Part Protection Commercial WPPC (M1)	*Albizzia falcataria*	L2M1S1	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
		Calliandra calothyrsus	L2M1S2	30	30	30	30	30	30	109	30	30	30	92	30	30	69	30	30	30	30	30	30
		Dalbergia latifolia	L2M1S3	20	20	240	20	20	20	20	20	22	20	178	20	87	20	20	20	240	20	20	20
	Hutan Tanaman Industri-Transmigrasi HTIT (M2)	*Albizzia falcataria*	L2M2S1	20	162	167	260	20	20	151	107	105	260	116	260	149	20	99	260	167	260	99	20
		Eucalyptus deglupta	L2M2S2	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
		Gmelia arborea	L2M2S3	150	30	30	30	150	30	30	30	30	30	30	30	37	30	38	30	30	30	38	30
	Industrial Grade Timber IGT (M3)	*Eucalyptus deglupta*	L2M3S1	20	20	20	134	20	31	20	20	20	20	20	126	20	21	20	20	20	134	20	31
		Eucalyptus urophylla	L2M3S2	10	10	10	10	10	10	109	10	10	10	61	20	10	10	10	10	10	10	10	10
		Gmelia arborea	L2M3S3	257	10	10	23	257	279	68	290	290	137	10	21	174	289	290	10	10	23	290	279
	Pulp Plantation PP (M4)	*Acacia mangium*	L2M4S1	40	265	40	40	40	127	40	40	40	40	40	40	40	88	40	167	40	40	40	127
		Eucalyptus deglupta	L2M4S2	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
		Eucalyptus urophylla	L2M4S3	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
3	Watershed Part Protection Commercial WPPC (M1)	*Albizzia falcataria*	L3M1S1	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
		Calliandra calothyrsus	L3M1S2	30	30	30	30	30	30	38	30	30	30	30	30	30	30	30	30	30	30	30	30
		Dalbergia latifolia	L3M1S3	20	20	32	20	20	20	20	20	20	20	32	20	20	20	20	20	32	20	20	20
	Industrial Grade Timber IGT (M3)	*Eucalyptus deglupta*	L3M3S1	20	20	20	43	20	43	20	20	20	20	20	20	20	43	20	20	20	43	20	43
		Eucalyptus urophylla	L3M3S2	119	68	118	90	68	90	125	68	68	68	118	119	68	90	119	68	118	90	68	90
		Gmelia arborea	L3M3S3	59	110	47	65	110	65	45	110	110	110	47	59	110	65	59	110	47	65	110	65
4	Watershed Part Protection Commercial WPPC (M1)	*Albizzia falcataria*	L4M1S1	30	30	30	30	30	30	30	30	30	30	30	30	30	58	30	30	30	30	30	30
		Calliandra calothyrsus	L4M1S2	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
		Dalbergia latifolia	L4M1S3	190	59	190	59	190	59	164	59	190	59	190	59	164	162	190	59	190	59	59	59
	Hutan Tanaman Industri-Transmigrasi HTIT (M2)	*Albizzia falcataria*	L4M2S1	20	20	20	20	20	20	46	20	20	20	20	20	46	20	20	20	20	20	20	20
		Eucalyptus deglupta	L4M2S2	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
		Gmelia arborea	L4M2S3	30	161	30	161	30	161	30	161	30	161	30	161	30	30	30	161	30	161	161	161
5	Hutan Tanaman Industri-Transmigrasi HTIT (M2)	*Albizzia falcataria*	L5M1S1	30	30	30	30	30	240	30	30	30	30	30	30	30	235	30	30	30	30	30	240
		Eucalyptus deglupta	L5M1S2	30	240	30	240	30	30	223	30	30	240	30	41	30	35	30	240	30	240	30	30
		Gmelia arborea	L5M1S3	230	20	230	20	230	20	37	230	230	20	230	219	230	20	230	20	230	20	230	20
			Total	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130

Notes: (a). 1\, 2\, 3\, . . . , 3 & 4\, 5 & 6\ were MINMAX formulations.
(b). 1/, 2/, . . . , 6/ were MINSUM formulations.

The last objective (max the readiness of plantation arrangement), E. deglupta (955 000 ha or 44.8 per cent), A. falcataria (610 000 ha or 28.6 per cent), and A. mangium (520 000 ha or 24.4 per cent) were the dominant species in the optimal solutions. Table 4.14 shows the other detailed species distributions under different objectives and formulations.

The second case (with MES) objective 1, all species were distributed in a fair balance except for E. urophylla (873 000 ha or 40.9 per cent). The other species were D. latifolia (337 000 ha or 15.8 per cent), G. arborea (320 000 ha or 15 per cent), E. deglupta (210 000 ha or 9.8 per cent), A. falcataria (190 000 ha or 8.9 per cent), C. calothyrsus (120 000 ha or 5.6 per cent), and A. mangium (80 000 ha or 3.7 per cent). Table 4.15 shows the other species distributions in details.

The last case (with MES and U/L limits) objective 1, four species, i.e. A. falcataria, A. mangium, and C. calothyrsus, E. deglupta were stable but the other species were altered, i.e. G. arborea (736 000 ha or 34.5 per cent from 320 000 ha or 29 per cent), E. urophylla (544 000 ha or 25.5 per cent from 873 000 ha or 40.9 per cent), and D. latifolia (250 000 ha or 11.7 per cent from 337 000 ha or 15.8 per cent). Tables 4.16 and 4.17 show the species details.

These techniques for solving multi-objective problems are based upon a search process which consists of feedback from the DMs, which further serves to guide the direction of the search. The outputs of this search are utilised for the next step, i.e. generating deliberated solutions by the LP-Simulator linkage.

Table 4.14. Forestland Allocation Solution by Species: Case 1 (Base Case)

Species	Forestland Allocation for Objective (000 ha)							
	1	2	3	4	5	6	MINMAX equal	MINSUM equal
A. falcataria	35	590	295	590	35	610	333	590
A.mangium	0	670	0	247	0	520	9	0
C. calothyrsus	0	552	5	8	0	0	538	0
D. latifolia	808	0	1155	0	843	0	0	255
E. deglupta	0	290	390	1240	0	955	90	35
E. urophylla	935	0	0	45	10	45	443	45
G. arborea	352	28	285	0	1242	0	717	1205
Total	2130	2130	2130	2130	2130	2130	2130	2130

Table 4.15. Forestland Allocation Solution by Species: Case 2 (with MES)

Species	Forestland Allocation for Objective (000 ha)							
	1	2	3	4	5	6	MINMAX equal	MINSUM equal
A. falcataria	190	502	337	430	190	570	344	447
A.mangium	80	535	80	80	80	167	80	80
C. calothyrsus	120	373	120	120	120	120	350	120
D. latifolia	337	80	853	80	342	80	94	80
E. deglupta	210	420	310	1190	210	963	210	210
E. urophylla	873	110	110	120	110	120	451	115
G. arborea	320	110	320	110	1078	110	602	1078
Total	2130	2130	2130	2130	2130	2130	2130	2130

Table 4.16. Forestland Allocation Solution by Species: Case 3 (with MES and U/L Limits)

Species	Forestland Allocation for Objective (000 ha)							
	1	2	3	4	5	6	MINMAX equal	MINSUM equal
A. falcataria	190	332	337	430	190	400	347	277
A.mangium	80	395	80	80	80	167	80	80
C. calothyrsus	120	120	120	120	120	120	207	120
D. latifolia	250	119	690	119	255	119	224	119
E. deglupta	210	420	210	872	210	559	403	210
E. urophylla	544	168	336	200	168	200	608	173
G. arborea	736	575	357	308	1107	565	262	1150
Total	2130	2130	2130	2130	2130	2130	2130	2130

Table 4.17. Forestland Allocation Solution by Species: Case 3 (with MES & U/L Limits) - continued

Species	Forestland Allocation for Objective (000 ha)																	
	1\	2\	3\	4\	5\	6\	1 & 2\	3 & 4\	5 & 6\	1 & 2\	3 & 4\	5 & 6\	1 /	2 /	3 /	4 /	5 /	6 /
	x '10' weight						x '5' weight			x '2' weight			x '10' weight					
A. falcataria	275	430	286	430	345	423	190	430	202	354	453	230	269	430	337	430	269	400
A.mangium	80	166	80	80	80	128	80	80	135	80	80	80	80	297	80	80	80	167
C. calothyrsus	120	120	182	120	120	159	120	120	120	120	120	233	120	120	120	120	120	120
D. latifolia	268	119	554	119	296	222	119	306	250	229	305	224	250	119	690	119	119	119
E. deglupta	210	420	401	643	210	554	342	488	270	260	581	639	210	420	210	872	210	559
E. urophylla	454	168	270	238	168	200	173	218	504	168	218	168	544	168	336	190	173	200
G. arborea	722	706	357	500	910	444	1105	488	649	918	373	555	657	575	357	318	1158	565
Total	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130	2130

Notes: (a). 1\, 2\, 3\,. . . , 3 & 4\, 5 & 6\ were MINMAX formulations.

(b). 1/, 2/, . . . , 6/ were MINSUM formulations.

4.6. The RMS-2020-FOLPI Linkage: Results Obtained

In this linkage, firstly, the data were generated by the RMS description file into the RMS genrep file. Then, this genrep file was transformed to correspond to FOLPI input data by the linkage utility. Five selected crop types were utilised, i.e. $L_1M_1S_1$ (crop type 5), $L_1M_1S_2$ (crop type 6), and $L_1M_1S_3$ (crop type 7), including two established crop types in location 1(crop types 8 and 9).

Then, FOLPI models were set up for four case studies. These case studies investigated such factors as:

(i) clearcutting of mixed, mainly young age and very few old age plantation crops;
(ii) alternative management strategies;
(iii) tradeoff between alternative management strategies, and;
(iv) optimisation capabilities deriving regional management strategies, e.g. 'what-if' considerations. Net present value (NPV) at 8 per cent discount rate was used as the objective criterion to maximise.

Table 4.18 shows NPV details and total volume and area cuts. Figures 4.2, 4.3, 4.4 and 4.5 show the volume and area cut distribution for the total region and for each individual crop type under those four case study scenarios. The area cuts followed the volume cut patterns due to young plantations in this preliminary case study. If NPV's were negative for MES calculations, FOLPI would not replant anything unless constrained to do so.

The yield fluctuations shown by case 1 unconstrained cuts (Figure 4.2) were not practical. There was a significant gap in area cuts for crop types 6 and 8.

Under case 2 (non declining yield for all crop types; Figure 4.3), the total crop type yield was smoothed over time but individual crop type yields and areas fluctuated except for crop types 4 and 6 (Figures 4.3).

Non declining yield for individual crop types was applied under case 3 which results in non declining yield and area cuts but this application has an end yield and area cut effect, especially for crop type 7 (Figure 4.4).

The fourth case limits the annual yield fluctuation to lie within 5 per cent, i.e. between 95 per cent and 105 per cent) and smooths its end effect (Figure 4.5).

Table 4.18.**East Kalimantan Plantation NPVs of Various Scenarios from FOLPI Runs**

Case #	Problem Structures	Management Practicality	NPV @8 per cent	Volume: 1.Total \✱ 2.NonPulp 3.Pulp	Area
			$million	000 m^3	000 ha
1	‣ new plantings ‣ replanting same crop types ‣ unconstrained cut	‣ opportunity costs for new plantings by increasing the NPV values ‣ to examine impracticality of harvest fluctuations	245 190	114 680 12 523 80 307	135
2	‣ new planting ‣ replanting same crop types ‣ non declining yield (NDY) for all crop types for total volume	‣ level of harvests for all three major crop types (as a regional wood supply) ‣ to avoid over-cutting	240 402	112 592 12 322 78 920	135
3	‣ new planting ‣ replanting same crop types ‣ non declining yield (NDY) for every single crop type for total volume	‣ level of harvests for every single crop type ‣ plantations with different and similar age-class distributions, effects on NPV values and level of harvests ‣ to avoid over-cutting and logistical problems, i.e. manpower and machinery schedules for every single crop type	226 088	110 233 11 982 77 177	135
4	‣ new planting ‣ replanting same crop types ‣ smoothed non declining yield (NDY)for every single crop type for total volume by ± 5 per cent	‣ ensuring changes in annual harvest levels are within acceptable levels in this case ± 5 per cent ‣ to examine area cut fluctuations	226 015	110 024 11 930 77 052	135

Note: \✱ total yield includes residuals (15 per cent).

Figure 4.2. Volume Cuts: Case 1
(unconstrained model)

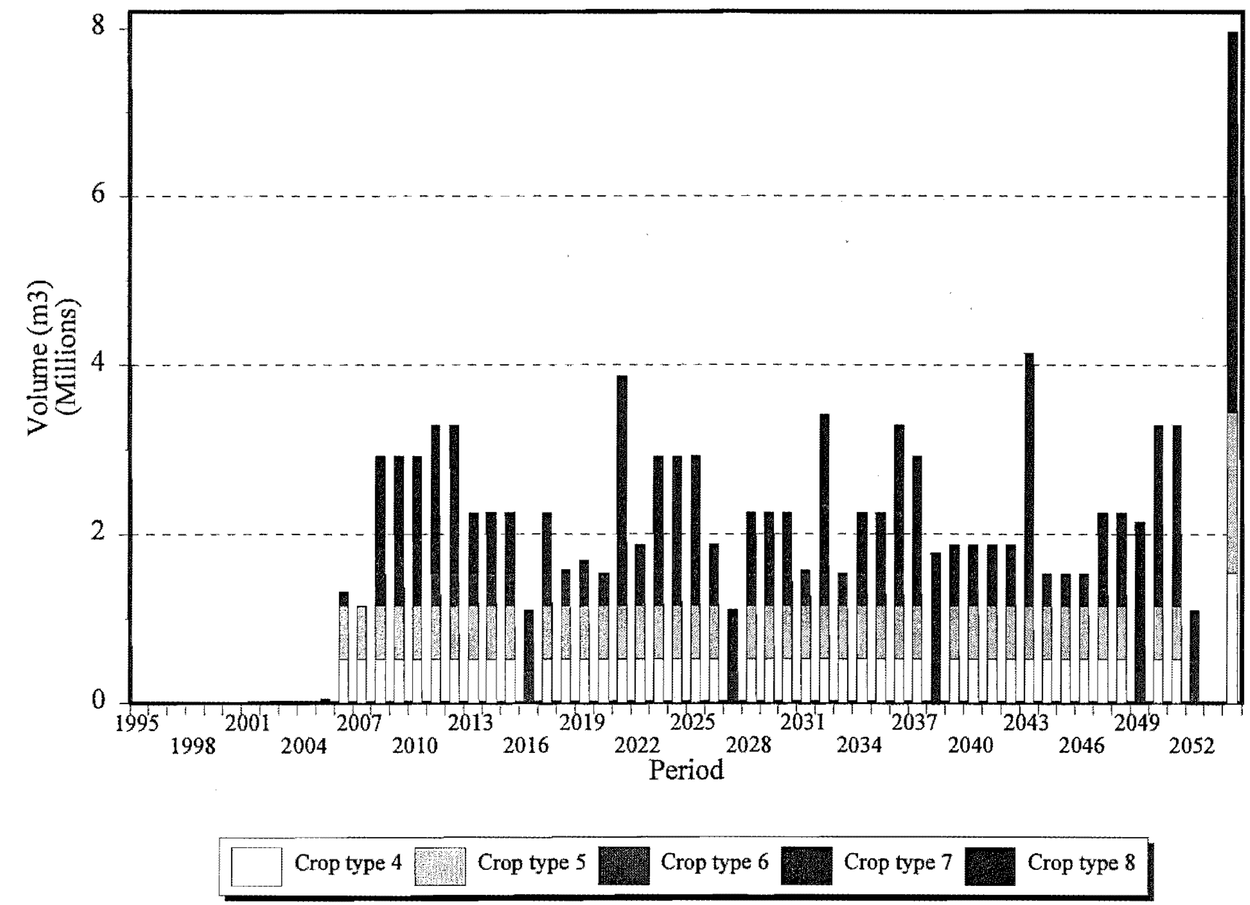


Figure 4.3. Volume Cuts: Case 2
(constrained model)

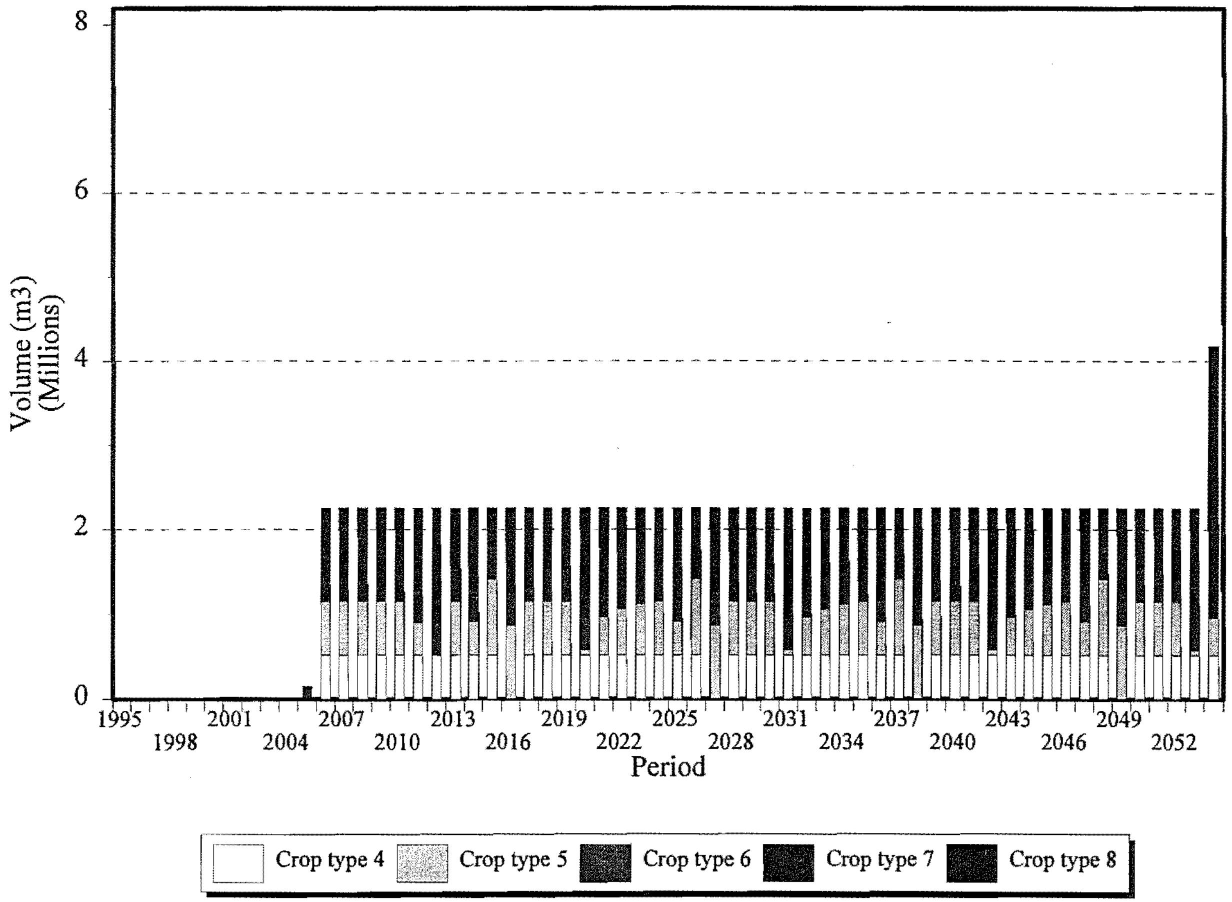


Figure 4.4. Volume Cuts: Case 3
(constrained model)

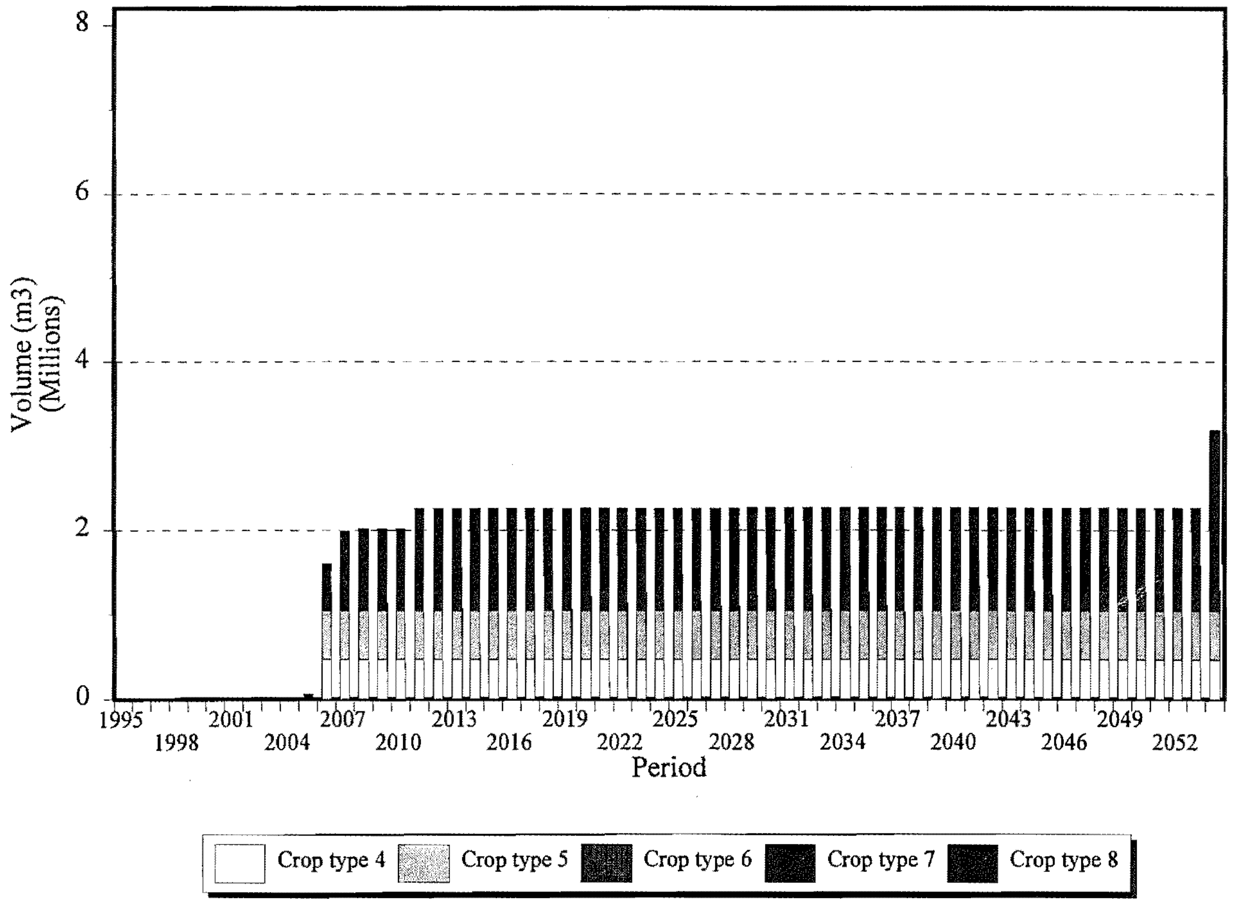
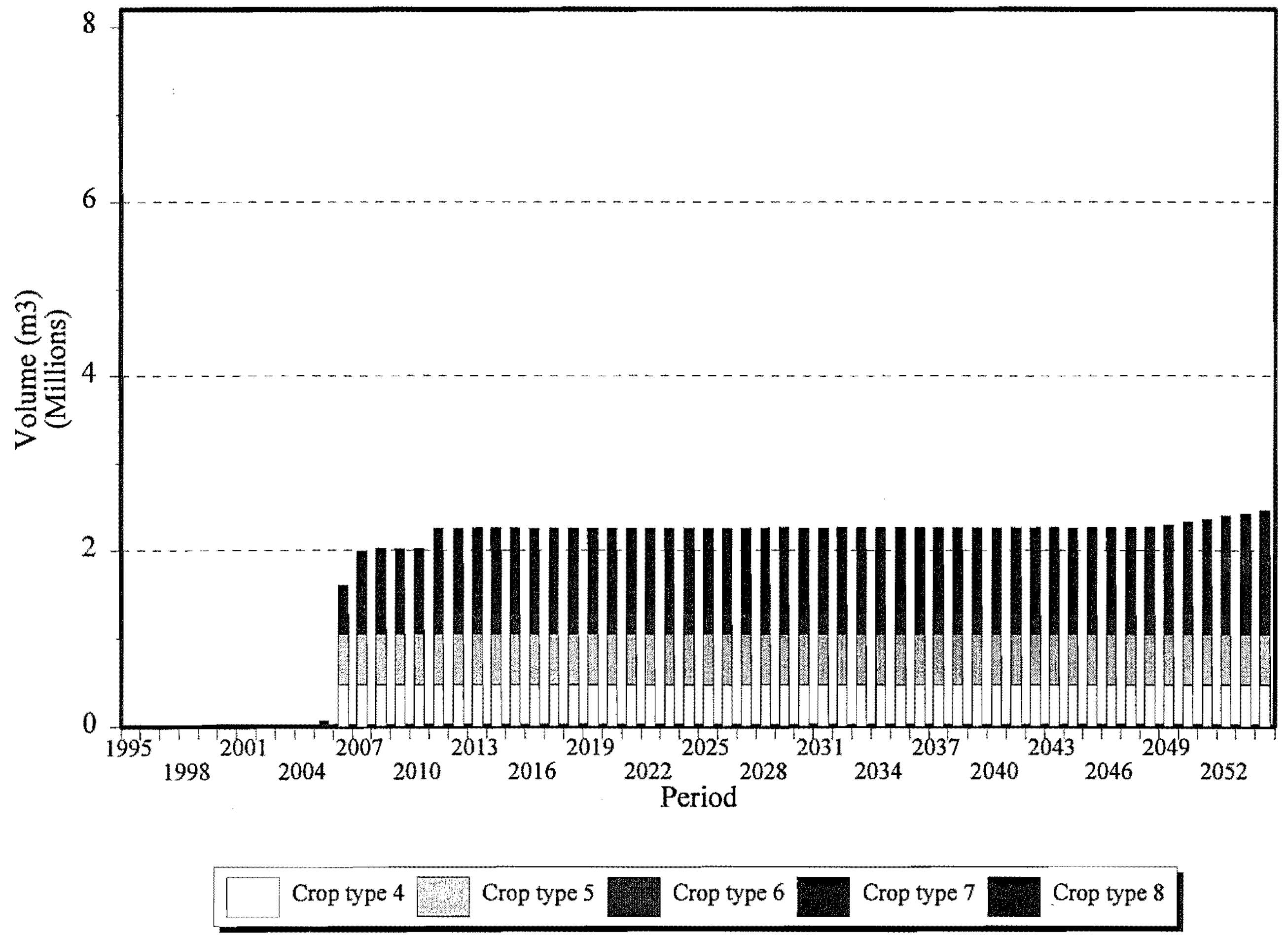


Figure 4.5. Volume Cuts: Case 4
(constrained model)



Those theoretical optimal solutions as calculated by FOLPI then were utilised as the benchmark for the simulator as a one way linkage. Simulation outcomes can be presented and discussed using any combination of several reports routinely produced in RMS-2020. Detailed report files were described in Section 3.3.3.2. In this study, the focus is on Sumrep, Genrep and Yieldrep to portray the results of applying specific management strategies as shown in Tables 20 and 21. These three summary reports describe the harvest taken, the regeneration done, the resource maturity consequences and the cashflow implications.

The simulation outcomes seen in this study indicate that there are obviously different consequences through choosing different management strategies, in this study largely associated with: (i) different level of wood supplies through year 2052, and; (ii) different target rotations. Year 2052 was selected in order to ensure that the consequences of each management strategy are fully considered.

The simulation outcomes seen in Tables 20 and 21 indicate that there are obviously different consequences through choosing different management strategies, in this case largely associated with the three target rotations employed. Each target rotation, namely 9, 10 and 11 years (for croptypes 4, 5, 7 and 8) and 14, 15 and 16 years (for croptype 6) is evaluated individually, to demonstrate that the output from optimisation can be utilised through simulation.

- **Simulation Outputs**
  - **9, 10, and 11-Year Target Rotations** (for croptypes 4,5, 7 and 8)

The 9-year rotation denotes the lowest NEV and NPV for all discount rates used (see Table 4.19). The magnitude of NPV and NEV values over the period 1995 to 2054 under three different discount rates is separately presented in Table 4.23.A. As expected, the various discount rates result in different values of NPV and NEV: the lower the discount rate, the higher the value of both NPV and NEV. The minimum and maximum value refer to annual values achieved in the progression towards a regulated condition over a planning period of 58 years (Table 4.20).

Table 4.19. **NPV and NEV Forecasts under various Discount Rate by 2052 (NZ$ million)**

Target Rotation (year)	Net Present Value (NPV) Discount rates(per cent)			Normal Exchange Value (NEV)		
	6	8	10	6	8	10
9	441	337	274	364	284	236
10	451	343	278	390	304	251
11	470	355	287	409	320	265
14	112	86	69	103	81	67
15	118	90	73	111	85	71
16	108	86	67	112	87	72

Table 4.20. **Summary of Simulation Output for Croptypes 4, 5, 7 and 8**

Measurement (unit)		Target Rotation (year) 9	10	11
■ ENF yield (000 m^3)	min	57	57	57
	max	2 081	2 081	2 041
■ ENF rotation (year)	min	1.8	1.8	1.8
	max	10	10	15
■ Harvest (000 m^3)	min	0.3	0.3	0.3
	max	2 197	2 253	2 023
■ NPV (NZ$ million)	at yr 2052	337	343	355
■ Minimum felling age	year	10	10	11
■ NEV (NZ$ million)	at yr 2052	284	304	320
■ Residual stock				
• oldest age	year	11	11	11
• average age	year	4.8	4.9	5.2
■ Net cash flow (NZ$ million)		1 274	1 269	1 187
■ Revenue total (NZ$ million)		2 918	2 907	2 755
■ Expenses total (NZ$ million)		958	955	929
■ Taxes total (NZ$ million)		687	683	639

Table 4.21. **Summary of Simulation Output for Croptype 6**

Measurement (unit)		Target Rotation (year) 14	15	16
■ ENF yield (000 m^3)	min	18	18	18
	max	246	244	248
■ ENF rotation (year)	min	1	1	1
	max	18	22	28
■ Harvest (000 m^3)	min	0	0	0
	max	249	236	236
■ NPV (NZ$ million)	at yr 2052	86	90	86
■ Minimum felling age	year	14	16	16
■ NEV (NZ$ million)	at yr 2052	81	85	87
■ Residual stock				
• oldest age	year	14	16	17
• average age	year	7.5	8.5	9.2
■ Net cash flow (NZ$ million)		267	248	232
■ Revenue total (NZ$ million)		545	509	482
■ Expenses total (NZ$ million)		134	128	126
■ Taxes total (NZ$ million)		144	133	124

For the 6 per cent discount rate the lowest NEV of NZ$ 364 million and the lowest NPV of NZ$ 441 million to the year 2054 are produced by the 9-year target rotation. The younger the trees are harvested, the lower is their value because of a reflection of log grade mixes within a tree at different ages. Consequently, the forest values in terms of both NPV and NEV are also lower. They represent measures of the worth of the forest when managed under this target strategy, which also results in terms of average age (4.8 years) as seen in Table 4.20. This average age is slightly different to the average age under a 10-year target rotation (4.9 years) compared with 5.2 years under a 10-year target rotation. This means that under an 11-year target rotation, the management strategy is to remove older ages of residual stock than do either the 9 or 10-year target rotations. Furthermore, the other residual stock information indicates that the oldest ages are the same (11 years). Figure 4.6 shows related information to the age, i.e. minimum and maximum age (in ENF), minimum felling age when harvestings take place, and information in residual stock at year 2052, for example, average age and oldest age.

Figure 4.7 shows the long-term ENF yields under these three rotation ages. For all rotations, their ENF yields increase steeply as new plantings taking place for the first ten years and after year 2009 provide yields accounting for just over 2 million m^3. The long-term harvests after year 2006 are quite similar between the 9-year and 10-year target rotations. However, the 11-year target rotation has several lower harvest levels (see Figure 4.8) caused by waiting for another one year ahead for harvesting. This creates several age class gaps (especially for age class 11 and older to be allowed to follow the harvesting patterns; no harvests below age class 11). The estimated allowable cuts under three different target rotations are shown by Figure 4.9. Figure 4.10 shows the long-term net cash flows under 3 different target rotations. These net cash flows follow the related activities in management strategy, i.e. planting, harvesting, replanting, *etc.* The detailed total cash flow at year 2052 are depicted by Figure 4.11.

Between target rotations of 9 and 10-year, they bear lower value of both NEV (NZ$ 284 million and NZ$ 304 million respectively) and NPV (NZ$ 337 million and NZ$ 343 million) at an 8 per cent discount rate (Table 4.20). The 9-year rotation produces the highest total net cash flow of any other rotation (Table 4.20). The second highest total net cash flow is the 10-year rotation which promotes a higher average age of felling than 9-year rotation. Therefore, based on the illustration above, 9-year and 10-year target rotations may be two likely choices for a management options, with their higher net cash flow between NZ$ 1 269 million and NZ$ 1 274 million. When managers and planners of the regional industrial forest plantation development wish to generate maximum profit, NPV can typically be used to decide what management options should be chosen. For this case study, the best optional rotation for managing these four croptypes 4, 5, 7 and 8 is likely to be 10-year. This rotation age has the following advantages:

- its NPV value is in between NPV values for 9 and 11-year target rotations;
- its long-term harvest level is the same as the 9-year rotation but better than the 11 year rotation;
- its stocked area by year 2051 has similar tendency as with the 9 and 11-year rotations but different to the 11-year rotation by year 2052 due to a longer one-year rotation for 11-year target rotation (see Figure 4.8.A).

Figure 4.6. Related Information on Age under 3 different Target Rotations *

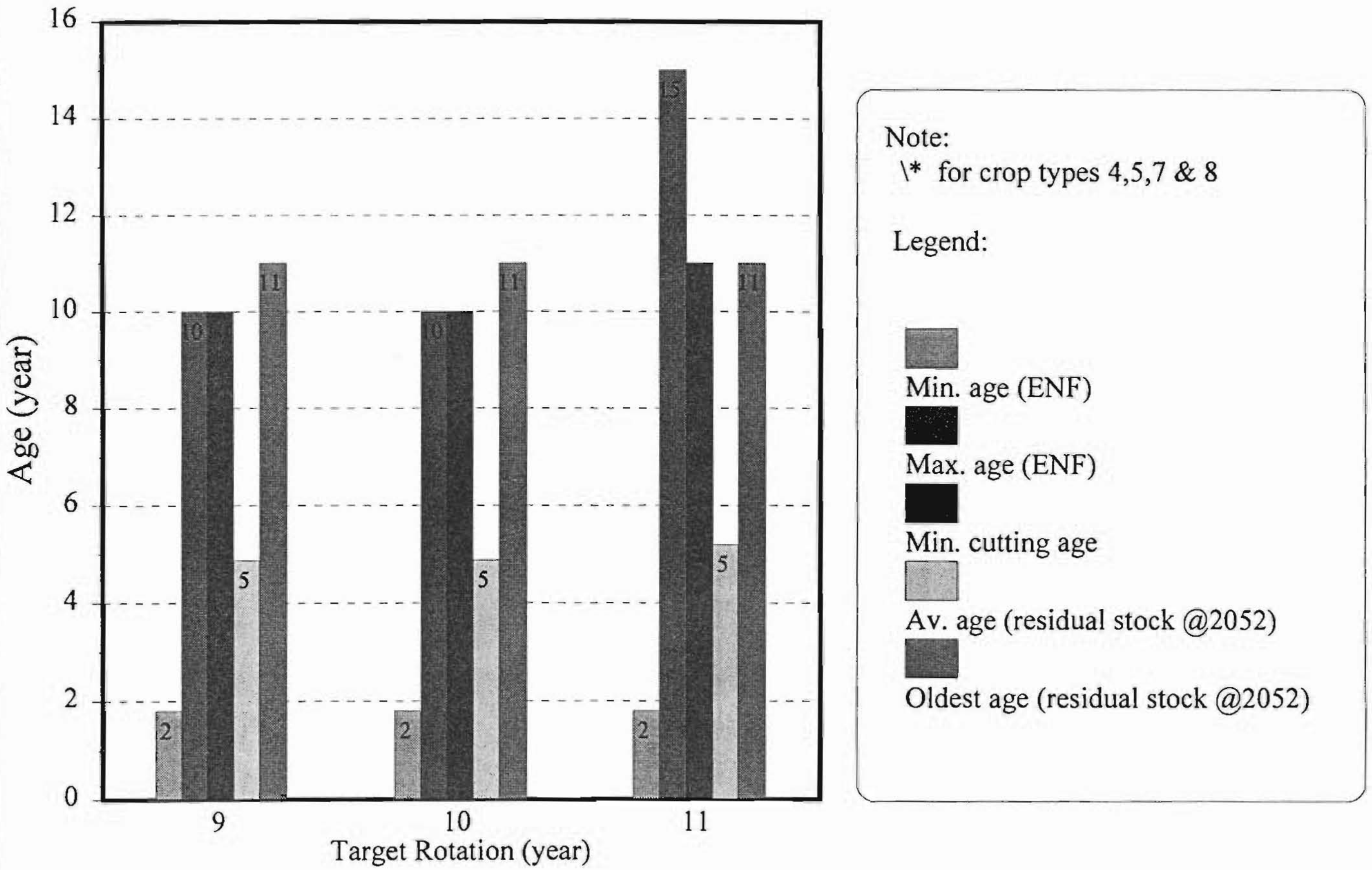


Figure 4.7. Long-Term ENF Yields under 3 different Target Rotations *

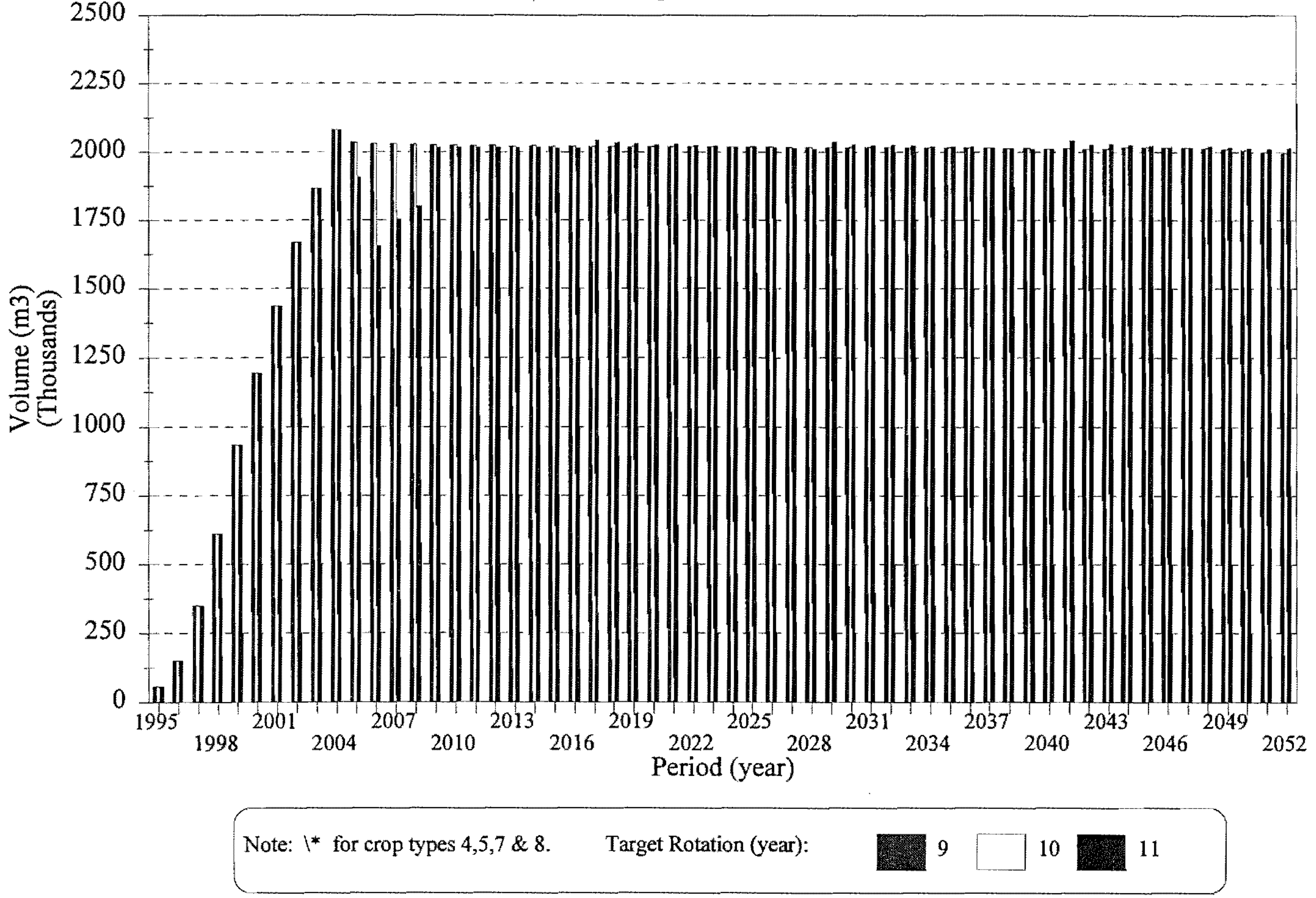


Figure 4.8. Long-Term Harvest under 3 different Target Rotations *

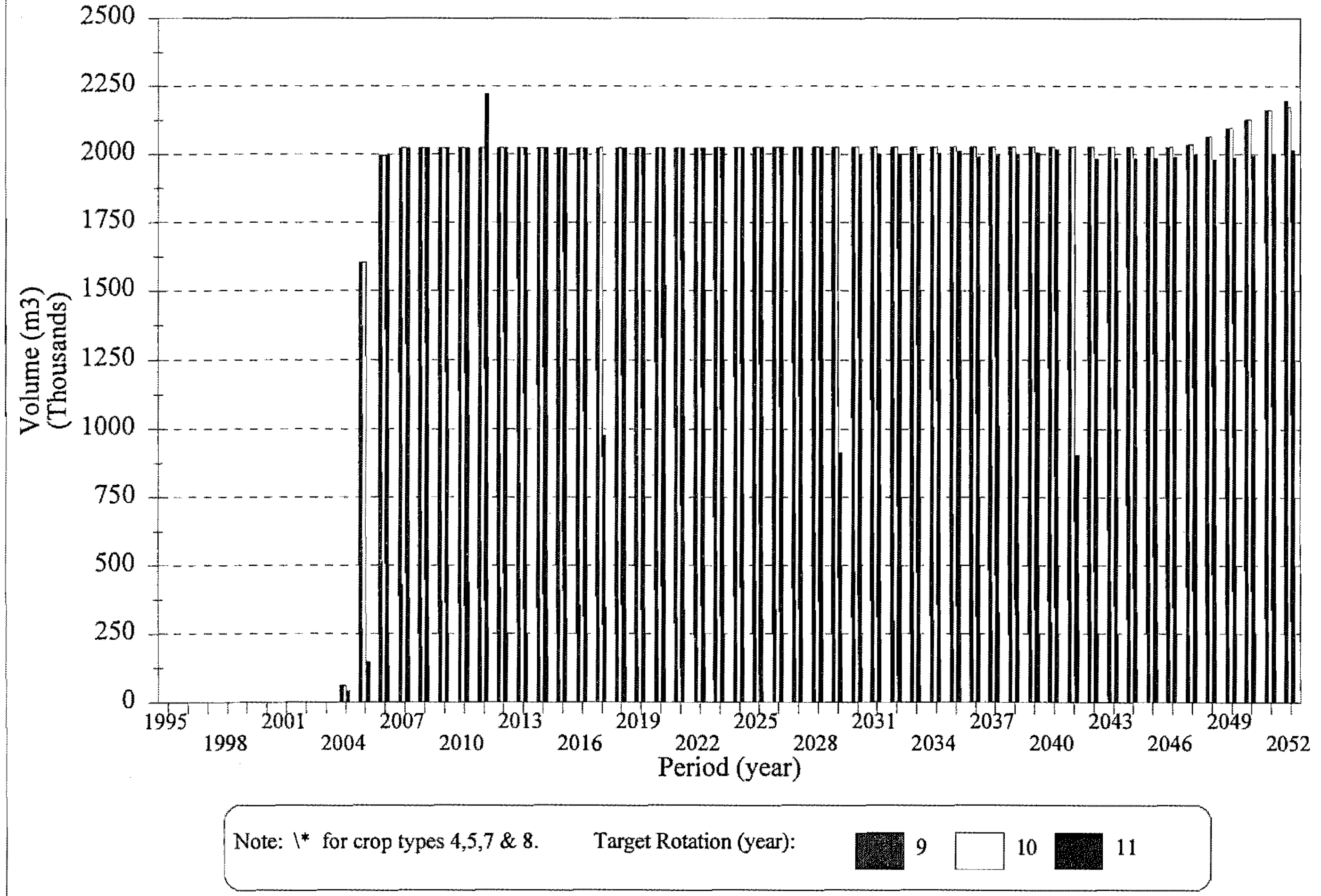


Figure 4.8.A. Stocked Area by Crop type by Year 2052 *

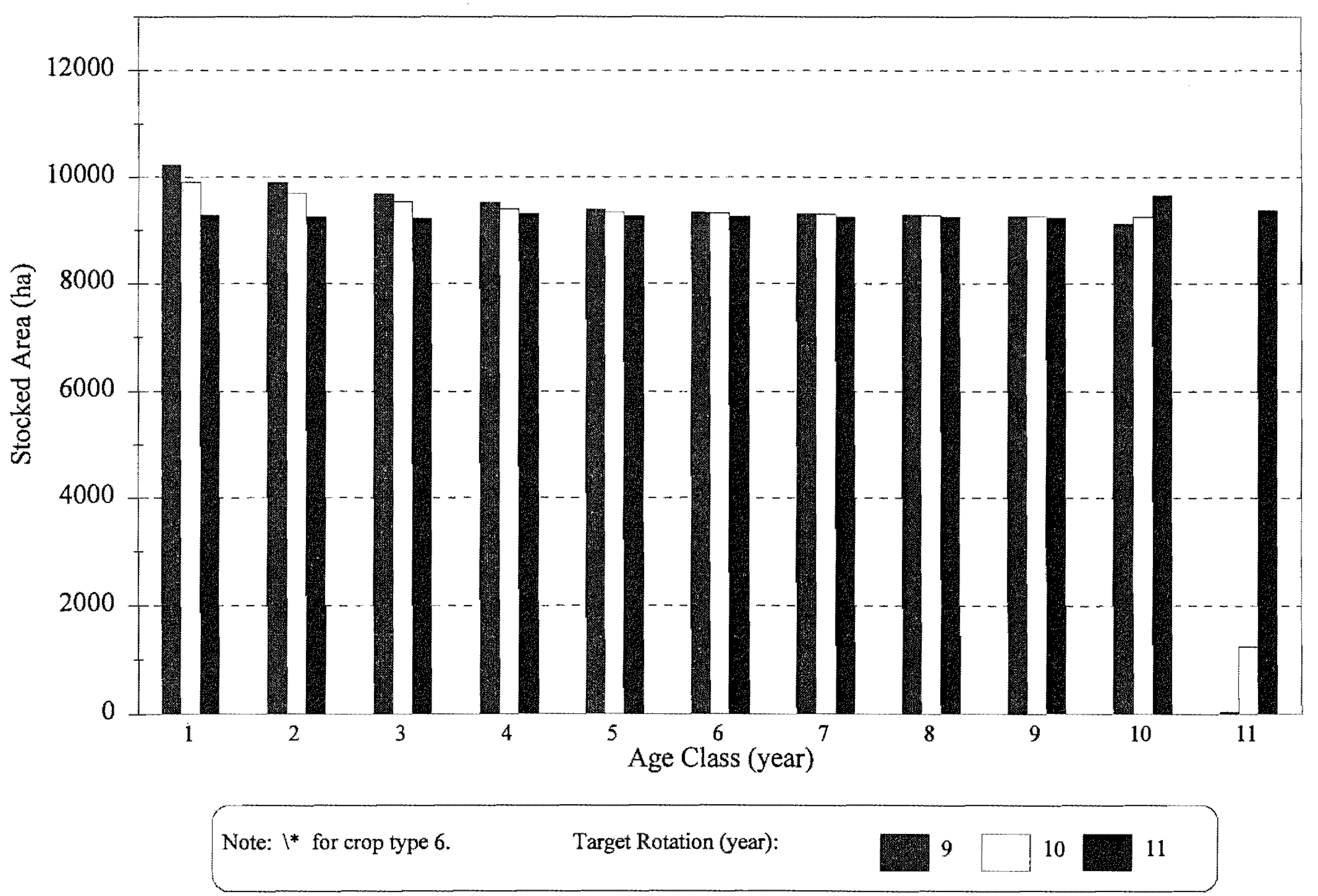


Figure 4.9. Estimated Allowable Cut under 3 different Target Rotations*

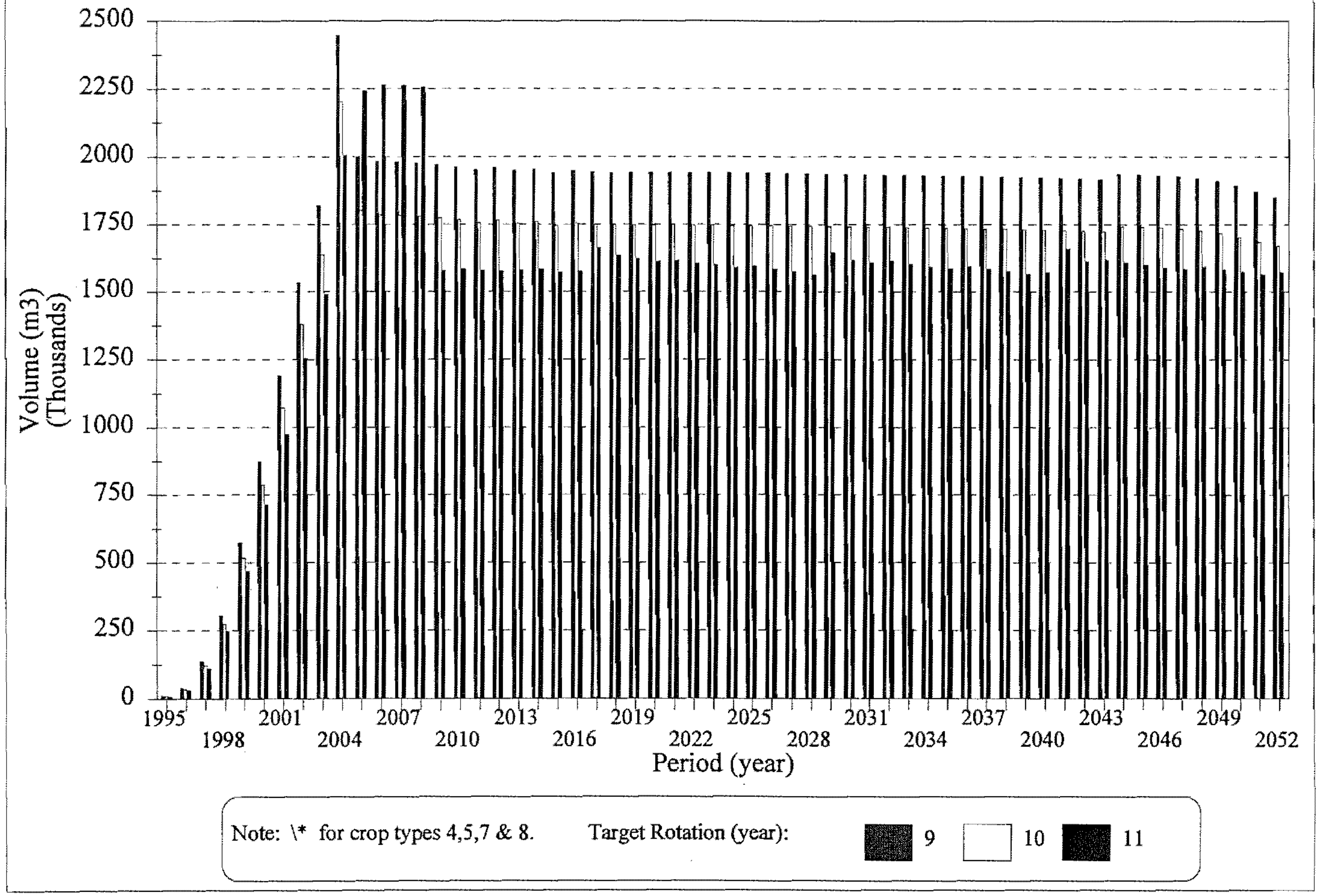


Figure 4.10. Long-Term Net Cash Flow under 3 different Target Rotations *

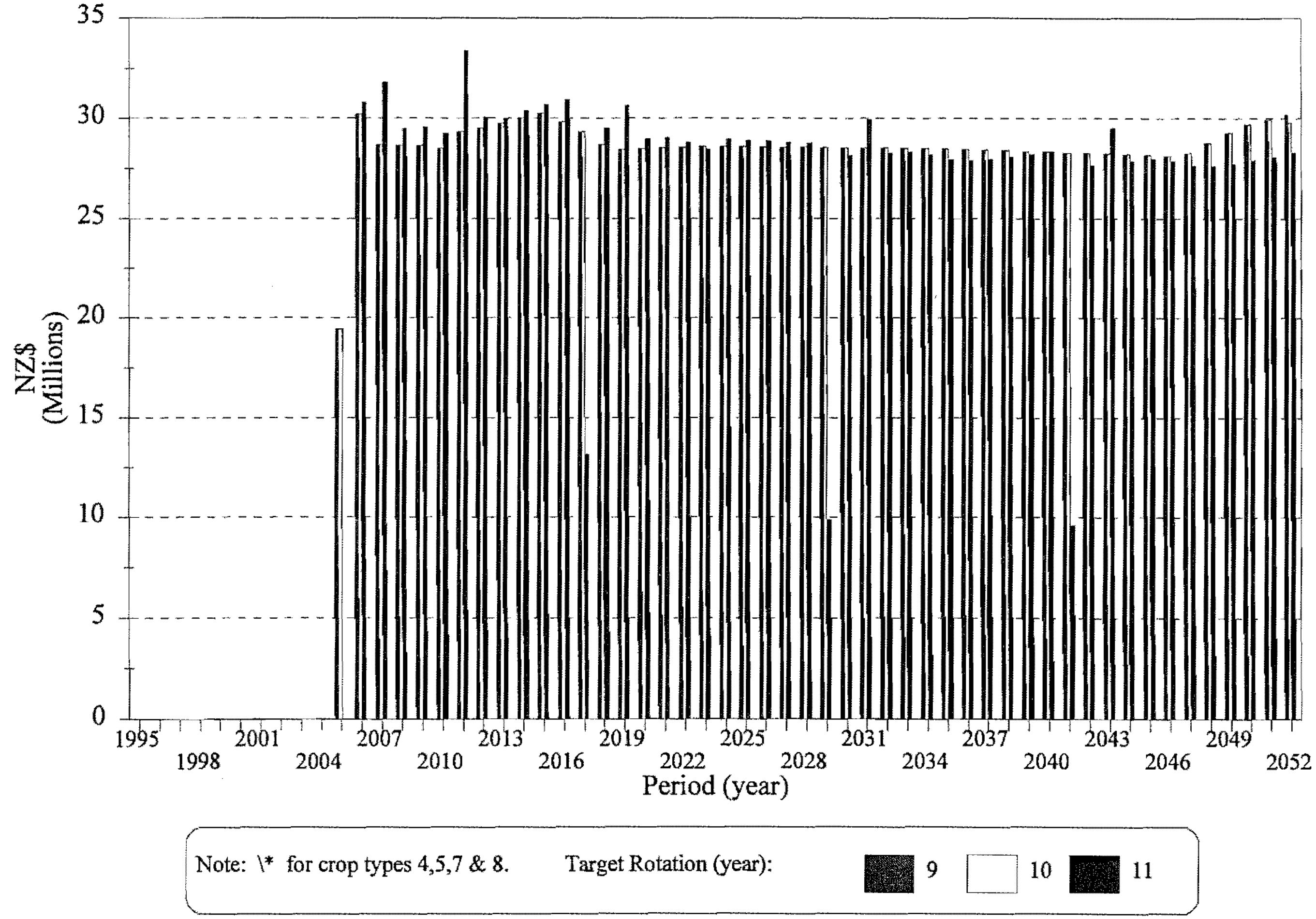
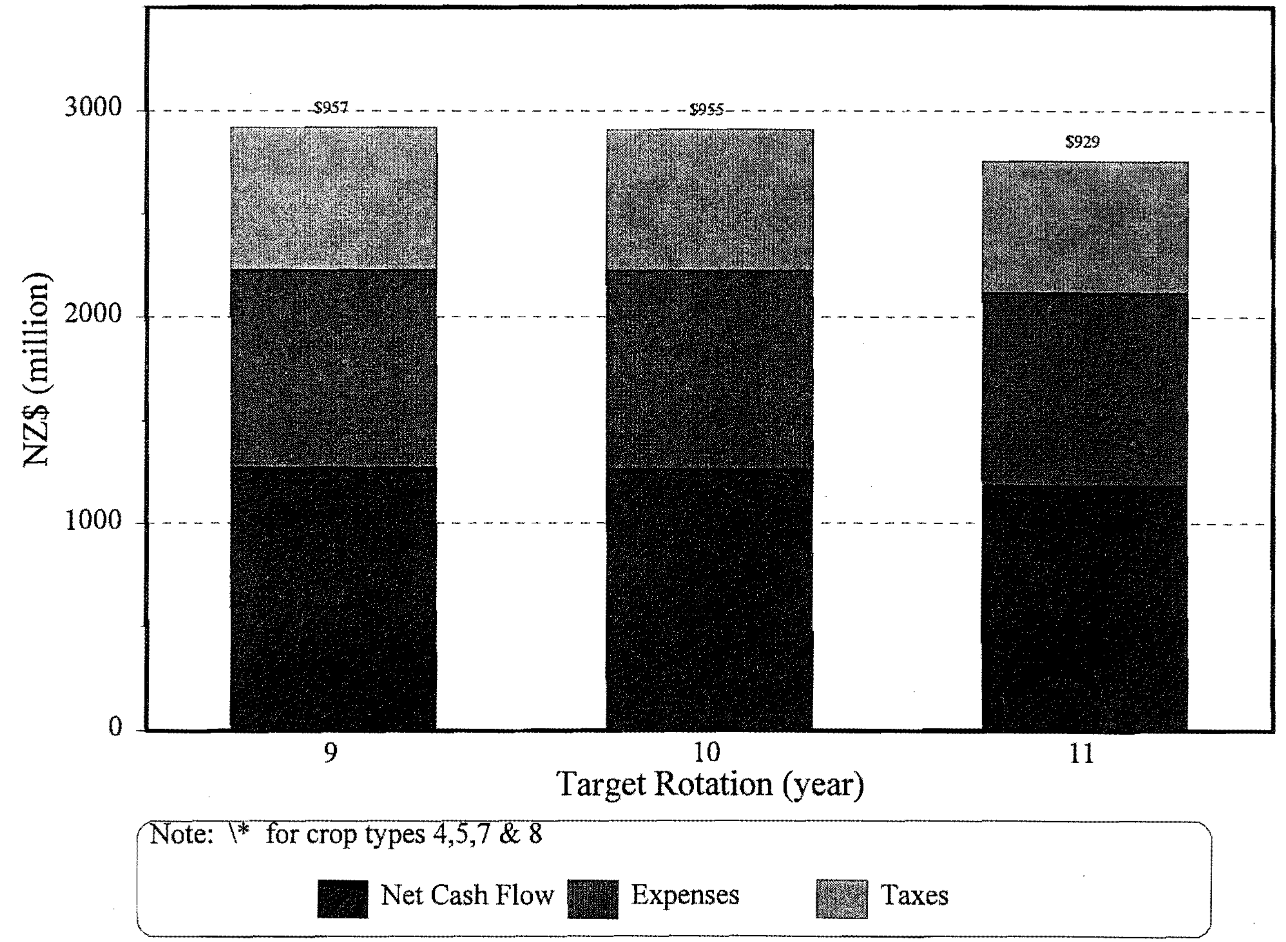


Figure 4.11. Total Net Cash Flow Year 2052: 3 different Target Rotations *



• **14, 15 and 16-Year Target Rotations** (for croptypes 4,5, 7 and 8)

A target rotation 14-years bears the highest net cash flow (NZ$ 267 million) at an 8 per cent discount rate due to higher volume harvest levels than other two target rotations (Table 4.21 and Figure 4.14). Nevertheless, it shows a lower NPV (NZ$ 86 million) and NEV (NZ$ 81 million) than for the 15 and 16-year rotations for all corresponding discount rates (Tables 4.23 and 4.25). It removes older ages of residual stock than either the 15 or 16-year rotations (Figure 4.14.A). The residual stock indicates that the oldest age is 14 years old, whereas the average of the whole forest is 7.5 years (Table 4.21;p.125 and Figure 4.12).

Figure 4.12 shows related information to the age, i.e. minimum and maximum age (in ENF), minimum felling age when harvestings take place, and information in residual stock at year 2052, for example, average age and oldest age.

Figure 4.13 shows the long-term ENF yields under these three rotation ages. For all rotations, their ENF yields increase steeply as new plantings taking place for the first couple of years and after year 2008 their yields vary between 150 000 and 250 000 $m^3 ha^{-1}$. The long-term harvests after year 2012 onwards for the 15 and 16-year rotations are quite similar (200 000 $m^3 ha^{-1}$ to 240 000 $m^3 ha^{-1}$. A target rotation of 14-year yields with various levels before its harvest level is in a slightly stable wood supply starting between year 2028 and 2052 (Figure 4.14).

Residual stocked areas by year 2052 for all target rotations are almost similar except for 16-year rotation for age class 11-years (see Figure 4.14.A). The two 14 and 15-year target rotations may be likely choice for management options regarding to their residual stocked areas. Figure 4.15 shows estimated allowable cuts under these three target rotations. This figure depicts slightly similar patterns to the harvesting levels (see also Figure 4.14).

Figures 4.16 and 4.17 show long-term net cash flows and total net cash flows by year 2052 under these three different rotations. Figure 4.16 also follows the similar pattern of the harvesting (incorporating planting and replanting) in Figure 4.14.

For this case study, the best optional rotation for managing crop type 6 is likely to be 15-years. This rotation provides:

- its highest NPV value (NZ$ 90 million); see Table 4.21;
- a more stable long-term harvest level than the other two target rotations (Figure 4.14).

These simple illustrations are useful for choosing the most suitable rotation age on the basis of both quantity and quality of wood supply (sustained yield that can be maintained) and financial matters. Additional information in the crop type requirement should be extended to keep pace with the field situation and represent more closely and reliably the existing regional resources.

Figure 4.12 Related Information on Age under 3 different Target Rotations *

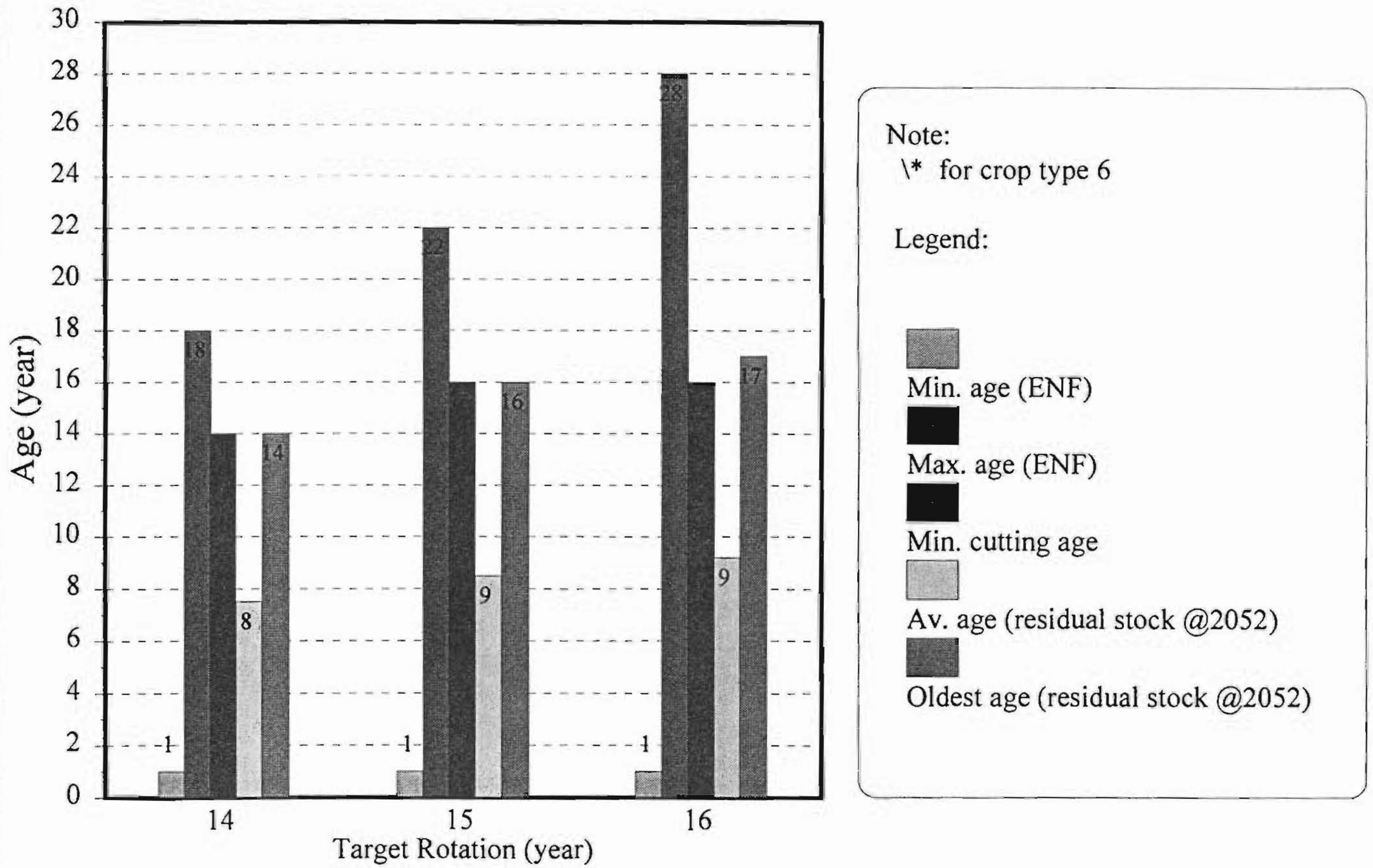


Figure 4.13 Long-Term ENF Yields under 3 different Target Rotations *

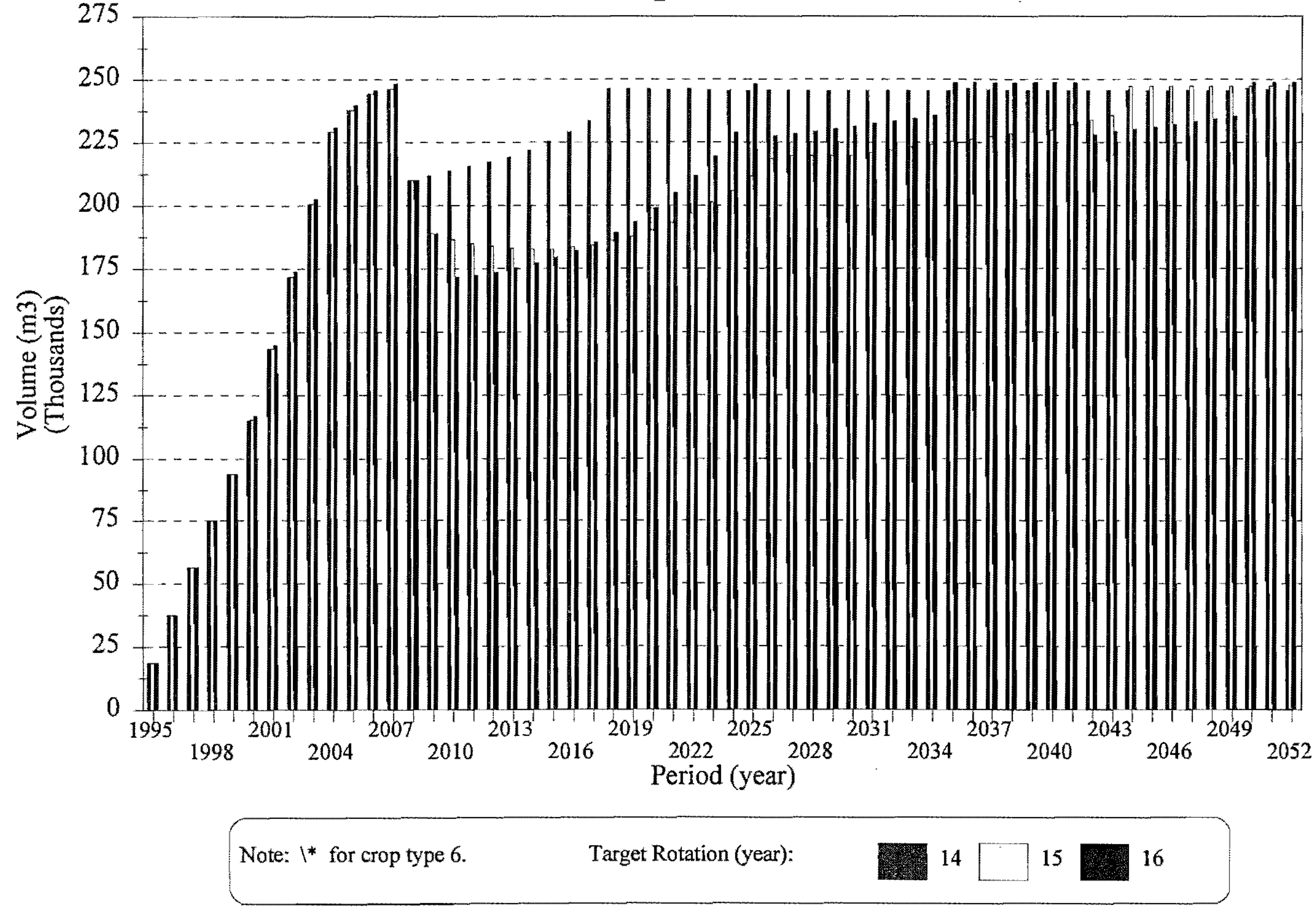


Figure 4.14 Long-Term Harvest under 3 different Target Rotations *

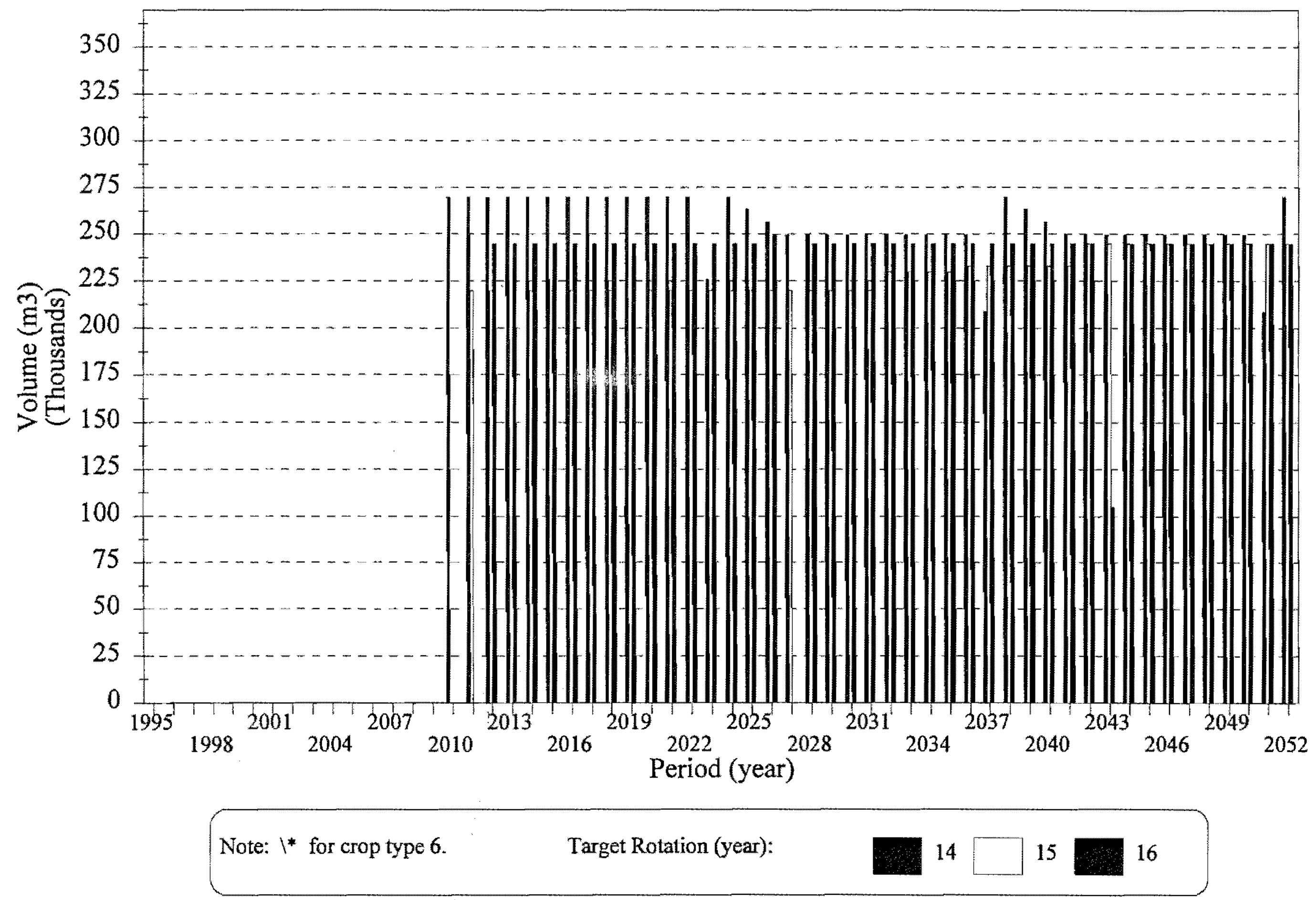


Figure 4.14.A. Stocked Area by Crop type by Year 2052 *

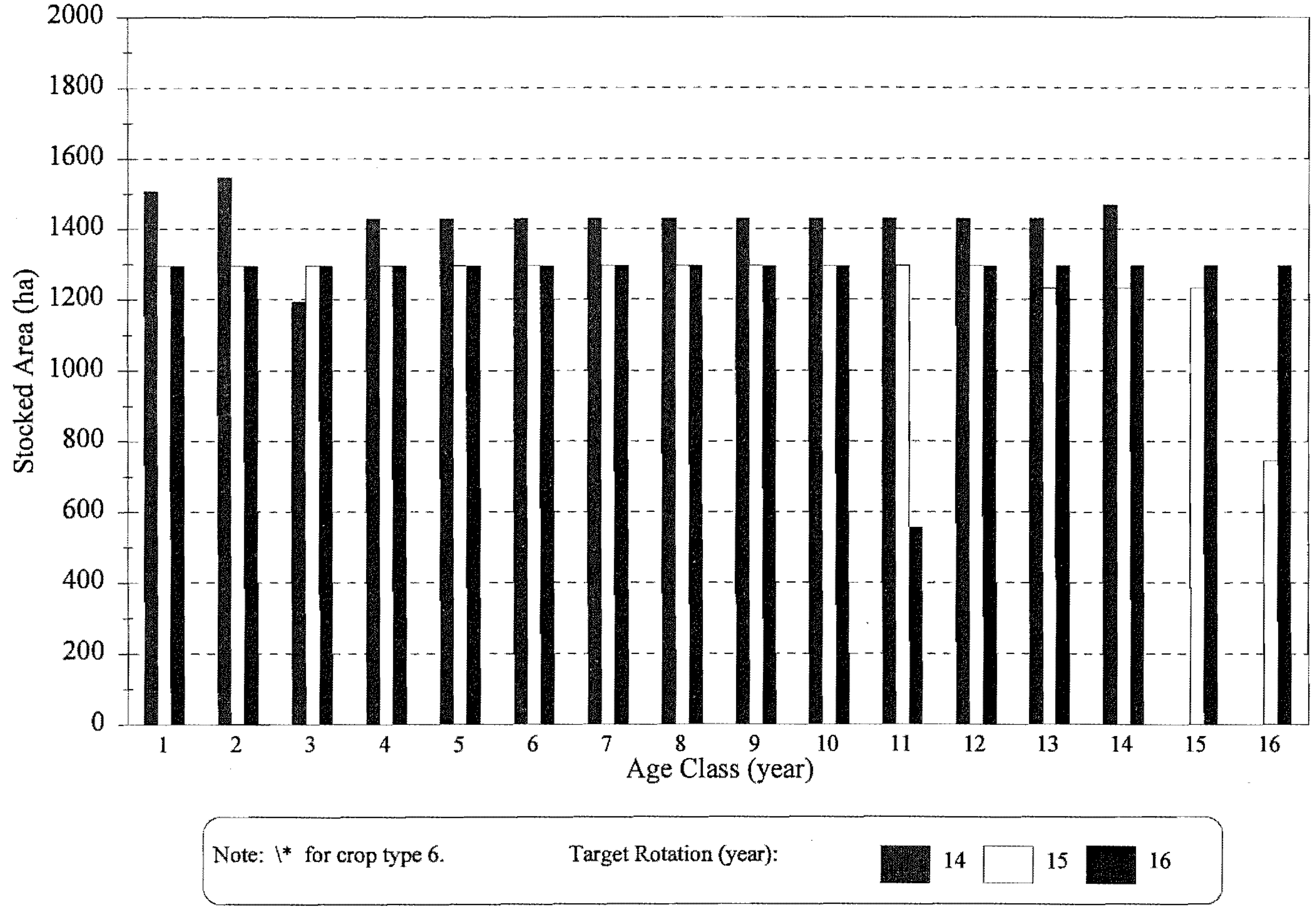


Figure 4.15 Estimated Allowable Cut under 3 different Target Rotations*

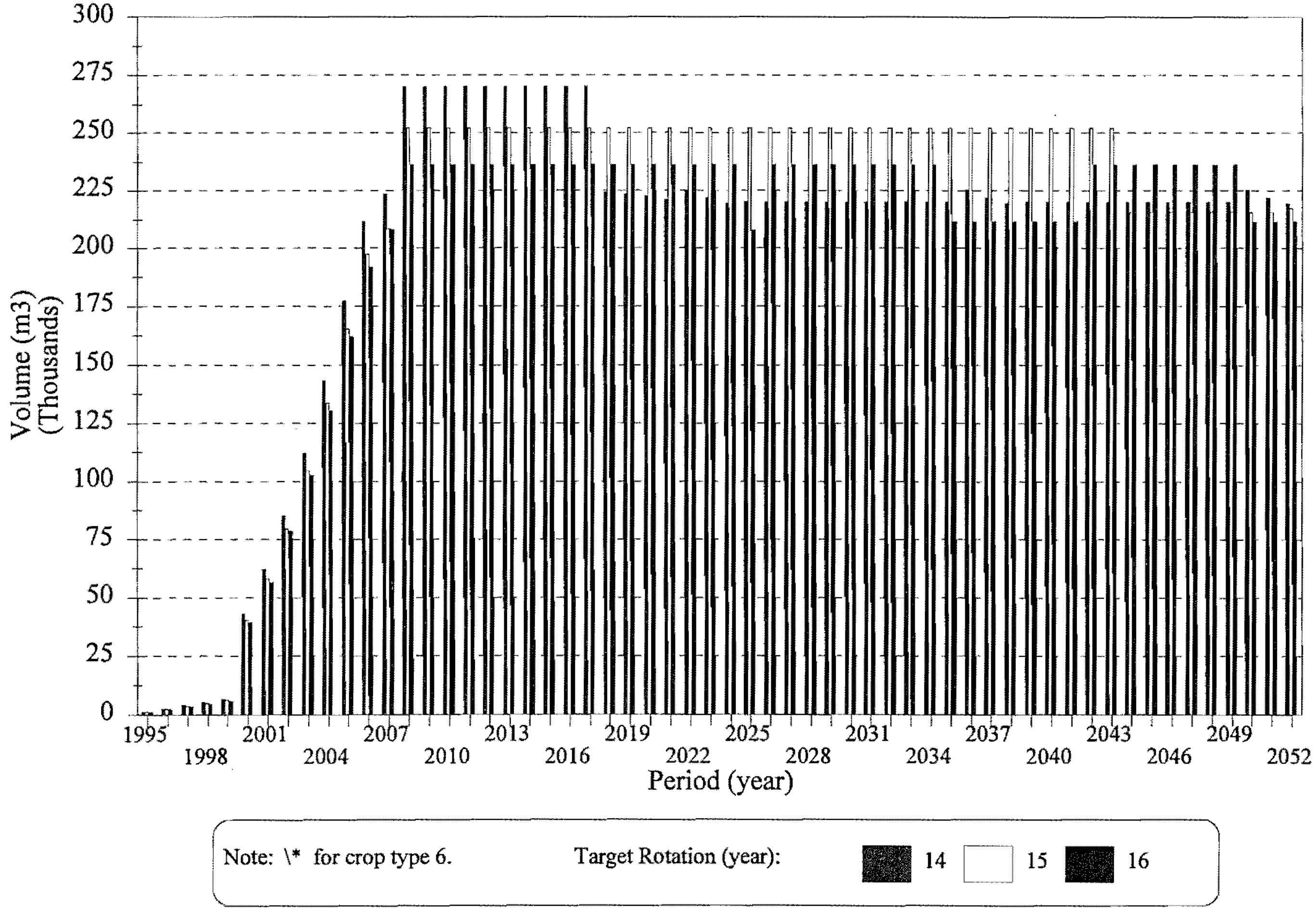


Figure 4.16 Long-Term Net Cash Flow under 3 different Target Rotations *

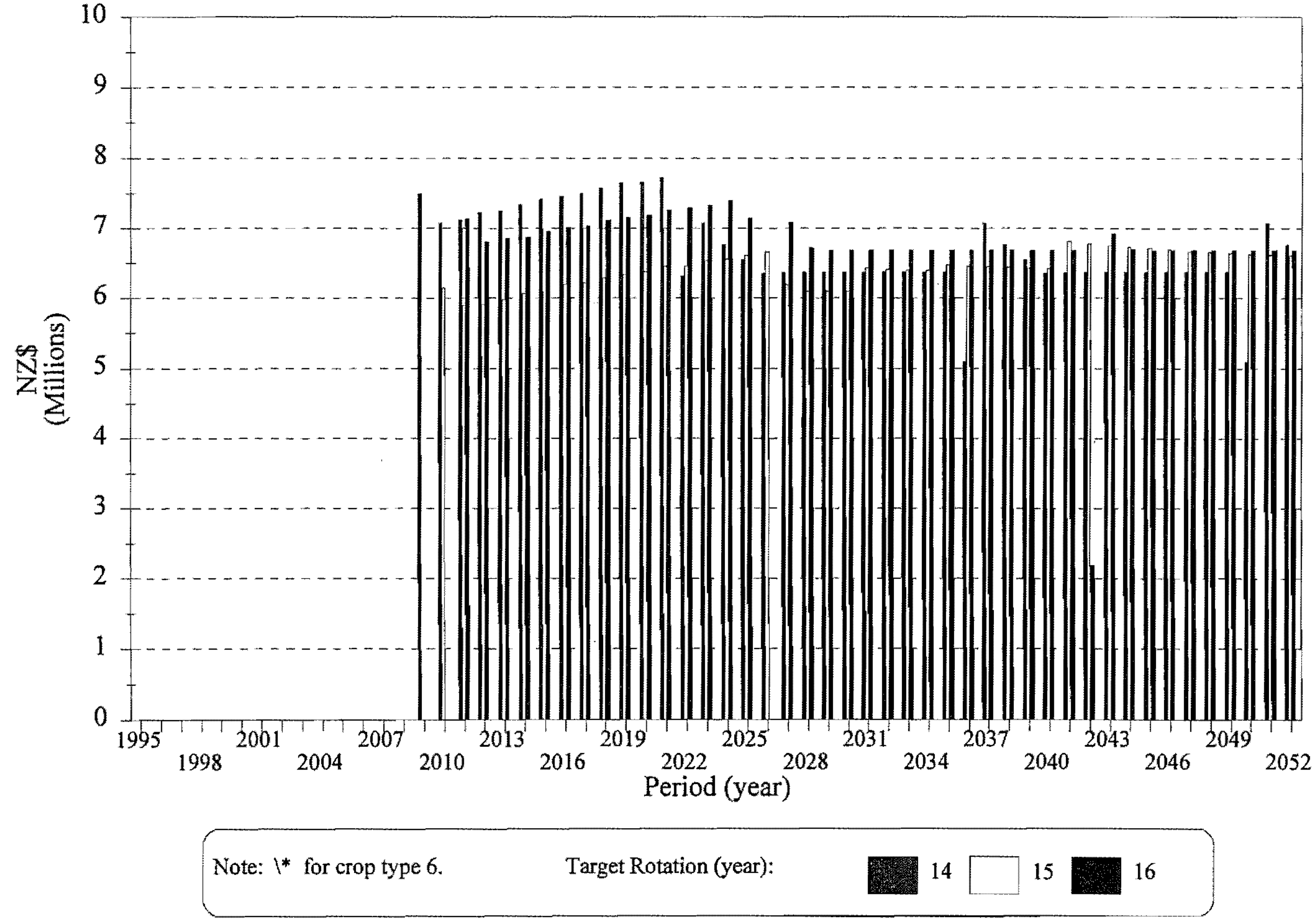
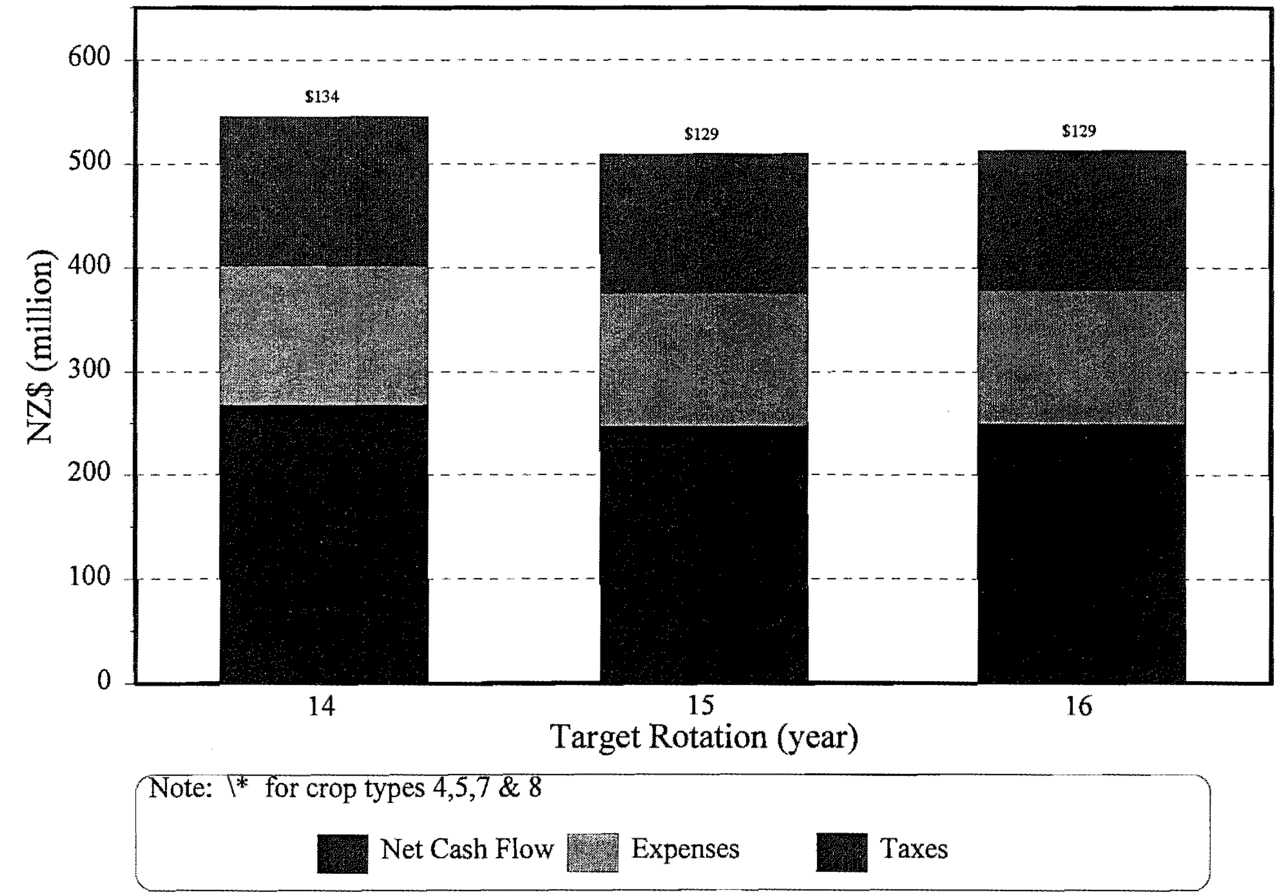


Figure 4.17. Total Net Cash Flow Year 2052: 3 different Target Rotations *



4.7. **Spatial database: Resource Allocation**

The proposed planning system that has been developed generates important spatial databases:

1. The second step (MES model) derived the minimum economic size due to management regime and species options. The resulting spatial databases are calculated with other data which were already stored;

2. the third step (forestland allocation model) obtained the forestland allocation model under different model assumptions and formulations. This step added its model solutions to the spatial databases such as in the distribution of location, management regime and species, and;

3. the fourth step (the linkage between optimisation and simulation) accumulated its spatial database with volume cuts, area cuts, revenues, costs, and the financial value of the resource (NPV) by crop type.

These spatial database can be transformed into Mapinfo software which is able to provide basic and practical resource visualisation, inquiries concerning management requirements, for example, cost and revenue data, spatial data. The GIS basic illustration are shown by Figure 5.8 (Chapter 5). Two major advantages in using recent developments in GIS tools that they:

(i) provide powerful and relatively inexpensive tools for storing, updating, retrieving, and analysing inventory and other forms of industrial forest plantations data, and;
(ii) provide a medium for communicating to non technical DMs and the wider stakeholder.

4.8. **Interaction with Managerial Requirements**

The management of industrial forest plantations can be viewed as the administration of a multi-product production process via multiple-objective problem solving in which this mix of objectives can and has accomplished continuous and spatial changes since its development. The magnitude of the roles of influence in setting out managerial policies and strategic plans, for example from the DM's point of view, the process of bringing stakeholders or public concerns (environmental, financial, social, production concerns) as external factors to the decision-making process can be applied at any level of the decision maker's side. It is certain that the rationale for imposing socially (for example, subsistence for the local community), environmentally (soil protection, watershed management), financially (revenues), technically (the establishment or development), or even politically governed constraints is to determine or limit these mix and other specific concerns.

This study did not attempt to examine the benefits that may confer any constraints' views but provided quantitative estimates of the effect of those restrictions in managing industrial forest plantations which might be acceptable to the decision makers (including policy makers) and stakeholders (including local community) through an interactive and quantitative decision-making process.

This planning system output can be contrasted with foreseen existing ones or can be visualised as a future structure of regional forestland that would result from the implementation of each strategy. In addition, the concept of concentrating intensive industrial forest plantation management on specific forestlands needs to be maintained by introducing various levels of slackening of constraints among environmental, social and financial concerns through this planning system. Finally, the ultimate value of the quantitative information generated from the planning system in this study is its ability to aid policy and decision-making processes through making informed choices in fundamental management decisions.

Chapter 5. Discussion

5.1. Modelling Framework

This study was conducted with the overall objective of developing a methodology for integrated and interactive modelling of regional industrial forest plantation development plans, specifically the crop type spatial allocations for strategic planning. Two different aspects to such sequential integration have been emphasised: one is the linkage between minimum economic size and forestland allocation model and the other is the linkage between simulation and optimisation models.

This planning system adopted is compatible with the technical and financial resources available. The clarity of those six objectives and about who is responsible for pursuing them and under certain conditions is essential in all cases.

5.2. Steps in the Planning System

The planning system, which has been developed here, outlines the six suggested procedural steps of regional industrial forest plantation development. Furthermore, The decision-making process should be broadened to include the elements determined in this planning system which are new in terms of its integral and interactive features for industrial forest plantation management at the regional level. In addition, these capabilities not only provide quantitative assessment of the justifications for choosing or making different options or resource allocations, but also several working values and implications.

5.2.1. Data Requirement

The first step is to ensure that minimum data and information requirements for developing and utilising planning models are collected, sorted and supplied. The major concern of this step is the process of developing data and information systems which can be used in optimisation (multiple-objective decision modelling) and simulation, with emphasis on the data types that will be needed and the possible data integration into the decision-making process. In addition, this planning system is dealing with spatial aspects in terms of availability of financial, technical and/or operational skill which, of course, differ from one location to another. Program priority should be introduced in order to allow long-term continuation of plantation establishment. Therefore, objective 6, maximising the readiness of the plantation arrangement, takes into account not only the decision maker's viewpoint but also that the stakeholder's, especially the industrial forest plantation applicants or wood processors.

5.2.2. MES

The second step is to determine the minimum economic size for any related management regime and species via spreadsheet-based minimum economic size model which makes it possible to provide explicit consideration of the most economic use of resources (management regime, location, and species) which may be a limitation for regional industrial forest plantation planning development.

Furthermore, industrial forest plantation investments must be justified and compared with other investments and within their investment options because of likely limited funding availability. The minimum or marginal size of investment must at least be equal to other developments. These total costs per hectare deriving from the MES model are also opportunity costs which are the values of selected crop types employed in their best alternative role.

Plantation sizes less than 10 000 ha have significantly greater percentage differences for total cost per hectare. Table 5.1 shows the percentage differences for total cost per hectare.

Total cost per ha differences seem to be at least 10 per cent higher for up to 5 000 ha plantation size, about 5 - 6 per cent for 10 000 ha plantation size, and below 3 per cent for between 20 000 - 150 000 ha plantation sizes.

Overall, larger plantation sizes have larger economic advantages over small plantation sizes. These indications support the view that small size diseconomies significantly increase average forestry costs (Cubbage, 1983). This statement is especially valid for pure production plantations, i.e. management regime 2 (HTIT: industrial forest plantation - transmigration), management regime 3 (IGT: industrial grade timber) and management regime 4 (PP: pulp plantation), where these three management regimes were developed to commit mainly production factors, i.e. non pulp and pulp log production for supplying markets or demands from the wood processing centres, it is less valid for the other management regime 1 (WPPC: watershed protection part commercial) which was set up to produce both production and protection functions.

Even though transportation costs are important in determining minimum economic size, this consideration has not been set up in the MODM model as one objective (minimising transportation distance between plantations and market and/or wood processing plants) due to findings that show minimising transportation distance has very little manoeuvrability and it would be discussed later. Therefore, in this dimensional space, such minimisation became a redundant objective in the model structure and the alternative optimal solutions varied within only a small range.

Literature on large forest plantations causing diseconomies is not abundant, but a Russian study concluded that management efficiency was best between 100 000 and 500 000 ha (Sudackov and Vitalev, 1967). The upper or maximum sizes of industrial forest plantations may vary and depend on forestland availability, the site uniformity and the rate of harvesting of those forestlands in any given location. This assumption is important for the structure in the forestland allocation model. Further discussion of it is covered in the third step of the planning system. In addition, a further basic consideration for the industrial forest plantation development is the financial or economical interests of the stakeholders and availability of financial and technical support within both government agencies and the private sector.

Table 5.1. **Total Cost per ha Differences for various Crop types and Plantation Sizes**

Crop type	Total Cost per ha Differences (per cent) for Plantation Size \✱		
	5 000 ha	10 000 ha	20 000-150 000 ha
Management *1*:			
Species *1* (M_1S_1)	12.8	6.2	0.1 - 3.0
Species *2* (M_1S_2)	12.9	6.3	0.1 - 3.0
Species *3* (M_1S_3)	10.9	5.3	0.1 - 2.5
Management *2*:			
Species *1* (M_2S_1)	10.8	5.2	}
Species *2* (M_2S_2)	10.9	5.3	} 0.1 - 2.5
Species *3* (M_2S_3)	10.8	5.3	}
Management *3*:			
Species *1* (M_3S_1)	10.9	}	}
Species *2* (M_3S_2)	10.9	} 5.3	} 0.1 - 2.5
Species *3* (M_3S_3)	10.8	}	}
Management *4*:			
Species *1* (M_4S_1)	12.8	6.2	0.1 - 3.0
Species *2* (M_4S_2)	10.9	5.3	0.1 - 2.5
Species *3* (M_4S_3)	10.9	5.3	0.1 - 2.5

Note: \✱ Total cost per ha difference to 200 000 ha plantation size.

The MES model outputs provide a wide range of options for any given management regime and species. This financial analysis as part of the decision matrix can then be carried over into another wider decision matrix, i.e. multi-objective planning, that is able to apply what-if analysis so as to provide a wider chance of numerical success.

5.2.3. **MODM**

The third step is the Multi-Objective Decision Making model for forestland allocation. The framework of the whole planning system demonstrates the capability and feasibility of resolution among several important and conflicting objectives through discussion and communicative decision processes. In other words, a methodology has been developed to analyse strategic options for plantation planning.

The MODM model is formulated via MINMAX and MINSUM goal programming formulations. This model characterises various features of industrial forest plantation development planning such as physical production, social, economic, environmental, and location aspects. Furthermore, this formulation has several advantages such as capturing the essence of the multi-objective decision making problem, seizing the entire range of feasible trade-offs among all objectives through parametric programming for deriving forestland allocations optimally, and providing important implementable and practical interests.

Some points related to this third step that add to existing procedures are :

1. The planning system and models developed combine all the multiple objectives and interests of all stakeholders in an effective and operationally practical way which is also quantitative and flexible.

   The foremost variations in regional influences between commercial objectives (objective 1 to maximise non pulp log production, 2 to maximise pulp log production, 5 to maximise revenue from the forestland for the organisation, and 6 to maximise the readiness of the plantation arrangements and non full-commercial objectives (objective 3 to maximise soil protection and 4 to maximise subsistence for local communities) are spatially displaced among crop types. Crop type = f (location, management regime, species) affects wood processing activities, establishment priority and feasibility of environmental and welfare consequences.

   It is apparent that any single objective alone could be reflected in the likely future plantation pattern, and that some combinations of them might be very different. These combinations depend in part on planning horizon or investment period. It is clear that if commercial objectives alone were allowed to dictate the development then non-commercial benefits (e.g. sedimentation) would be the major loser through loss of representation of its value or the other way around. For example, under case 3 (with MES) with MINMAX formulation (see Table 4.8.C), the emphasis was given to objectives 1 (max non pulp log production) and 2 (max pulp log production) of weights "5", these two objective values of 92.2 per cent each of their percentage achievements while objective 3 as the non commercial objective was 77.6 per cent while the other non commercial objective (i.e. objective 4 max the subsistence for the local community) was also improved (92.5 per cent). Because this objective benefitted partly from those two commercial objectives. In addition, the value for subsistence was improved through establishing those commercial plantations as a compounding effect. In addition:

   (i) this explains why E. deglupta emerges on Tables 4.14, 4.15, and 4.16 (p.106; check) as a dominant species option which maximises the contribution to "subsistence of local community" (maximising objective 4 in isolation) and is almost opposite to the WPPC regime which generates less employment opportunity, and;
   (ii) sedimentation could also mean low of fertility, etc and loss of productivity - negative aspects for a commercial investor.

Other goal programming formulations such as lexicographic goal programming (or one of its variants) have been considered but disregarded as the main goal programming formulations for this study. Lexicographic GP has a drawback, i.e. naïve prioritisation which would lead to the misrepresenting the reality of the problem in the model formulation (Amador and Romero, 1989). If the priorities were given more in commercial objectives than non commercial ones, therefore, this might cause higher priority (commercial objectives) to always determine the lower priority (non commercial objectives). This because of an inherent lexicographic ordering that assumes the LP problem comprising the minimisation of the first component of the vector achievement is subjected to conforming constraints and goals. These conformities have alternative optimal solutions. Therefore, if the last commercial objective (e.g. objective 2: max non pulp log production) has no alternative optimal solutions, then the other lower priority goals (i.e. non commercial objectives) would be redundant.

This study has tested the redundant seventh objective, i.e. minimising transportation distance from the industrial forest plantations to the demand points or wood processing plant centres. A practical difficulty in the establishment of this objective was that is was very limited in the manouverability of its objective functional values, therefore, this objective did not play an actual role in the optimisation process or an ornamental role (Amador and Romero, 1989). On the other hand, in terms of the overall forest resources (i.e. natural and plantation forests) there may exist interconnected transportation facilities (roading or water transportation) shared amongst different forest ownerships which may influence decision-making. Thus, further research in this area should be carried out in order to anticipate the likeliness of transport infrastructure availability and limitations. Such initial research has been done by Nasendi (1984).

In terms of forestland allocations (MINMAX formulation with weights "5" for objectives 1 and 2 compared with MINMAX formulation with equal weights of "1", all those commercial management regimes in location 1 M_1 (WPPC), M_3 (IGT), and M_4 (PP), were allocated the same forestland solutions, 80 000 ha, 365 000 ha, and 120 000 ha respectively; in location 2 more forestland were distributed: for M_3, 287 000 ha from 197 000 ha and for M_4, 240 000 ha which was the same size. This indicated that more non pulp and pulp log production (for higher commercial values) were gained from more forestlands in M_3 than dedicated M_4 itself. On the other hand, non commercial management regimes were re-distributed: for M_1, 80 000 ha from 159 000 ha and M_2: 201 000 ha from 190 000 ha (Tables 4.9.C and 4.9.D). In locations 3, 4, and 5 the forestland allocations changed little due to their combination between the commercial and non commercial management regimes in those particular locations.

If the non commercial objectives were given higher weights of "5" (i.e. objectives 3 and 4) than the commercial ones, the percent of achievements for non commercial objectives were better off at 90.2 per cent each compared with 77.1 per cent and 86.1 per cent for commercial objectives 1 and 2 alone emphasised. Regarding the same comparison as the previous paragraph, its forestland allocations for non commercial management regimes were only held: for example, in location 1 where M_1 increased from 80 000 ha to 214 000 ha, M_3 decreased from 365 000 ha to 231 000 ha, and M_4 was the same at 120 000 ha; in location 2 where M_1 decreased from 159 000 ha to 121 00 ha to compensate the higher non commercial values through M_2 which increased from 201 000 ha to 310 000 ha, M_3 decreased from 197 000 ha to 126 000 ha, and M_4 was the same at 120 000 ha (Tables 4.9.C and 4.9.D). In locations 3, 4, and 5, the forestlands were allocated with only small alterations to the combinations of M_1 and M_3, which slightly decreased and increased by 8 000 ha to 80 000 ha and 198 000 ha respectively (location 3); M_1 and M_2 decreased and increased by 5 000 ha to 119 000 ha and 201 000 ha respectively (location 4), and M_1 was the same due to its single management regime option in location 5.

The overall management regime distribution (total forestland as 2 130 000 ha) was shown partly for objectives 1, 2, and 3 under case 3 and MINMAX formulation with weights "10" and "100". Figure 5.1 shows the four single management regime distributions resulting from various management regime combinations in any location that could possibly occur in practice. For example, under objective 1, M_1 was reduced by 7 per cent (to 742 000 ha), M_2 and M_3 were increased by 22.6 per cent (276 000 ha) and 0.1 per cent (873 000 ha) respectively, and M_4 was stable at 240 000 ha; under objective 2, M_1 and M_2 were stable whereas M_3 was decreased by 19.2 per cent (520 000 ha from 644 000 ha) and M_4 increased as expected by 8.7 per cent (to 450 000 ha from 326 000 ha); under objective 3, M_1 and M_2 increased by 6 per cent (1 217 000 ha) and M_2 by 10 per cent (260 000 ha) while M_3 and M_4 were stable at 649 000 ha and 511 000 ha respectively.

These forestland allocations with various formulations and weight structures allow trade-offs in terms of the objective function values, forestland allocations and other considerations such as species distribution. The main advantage of heuristic interpretation and refinement through simulation is that decision makers (incorporating analysts and experts) and stakeholders assign weights to each measure and obtain a unique composition number for each derived alternative. This method is simple and easy to use and flexible, to permit modifications as decision makers and stakeholders gain expertise in its use.

2. Some trade-offs and possible conflicts that characterise different plantation development mechanisms and patterns are shown here as major implications in the choice of regional objectives. They are very important effects in weighing advantages and disadvantages. Possible discussion through reconciliation of forestland suitability and availability, different objectives, existing plantation development patterns and description of some of the major considerations surrounding plantation decisions spots, should consider:

    (i) spatial management regime patterns;
    (ii) regional or locational production targets;
    (iii) species distribution, and;
    (iv) plantation size distribution.

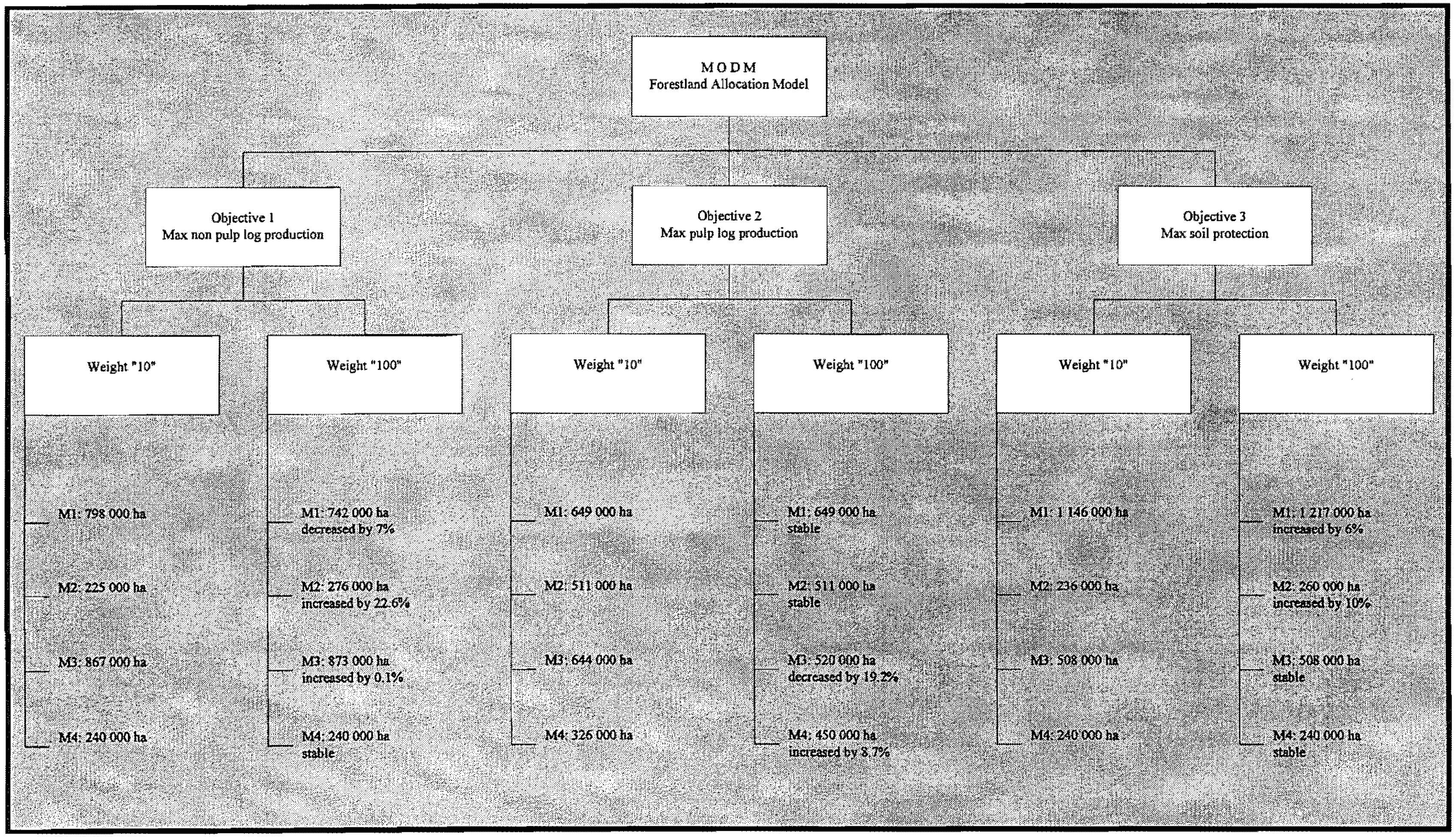


Figure 5.1. Forestland Allocation Model Solutions for Three Objectives under Two Weights: MINMAX Formulation

The first aspect can be viewed in Figure 5.2 depicting the forestland allocation solutions under three different assumptions (cases 1, 2, and 3) with MINMAX equal weight "1" formulation. Spatially speaking, under case 1 (base case/without MES) the forestland allocation tends to be far away from the wood processing centres or outlets such as main harbours. In contrast, under cases 2 (with MES) and 3 (with MES and U/L limits), the allocations produce a fairer balance among the various crop types.

The regional or locational production targets is the second aspect that alters the allocation. Non pulp log and pulp log production may be considered as lower and upper limits. They could be initially very low and very high respectively depending on log supply commitments to any given markets or wood processing plants.

Experience with especially the MINMAX formulation, suggests that those two limits can be altered closer toward each other; therefore, more scenarios are automatically examined. This alteration influences the crop type distribution for any given location to satisfy at the same time those (in this case) lower bounds and forestland upper limits for forestland availability. These regional or local limits would be required when each implementation occurs. It requires disaggregation of resource output targets and development (Fox et al., 1989). Only log production constraints were applied, while others such as financial and environmental constraints (which also would be different for different locations) were not addressed in this study.

This study was focused solely on making trade-offs (via weightings) for managing the forestland by assessing multiple objective functions for the entire case study region. The spatial sequence of forestland allocation was excluded in the model specifications. Considering the spatial sequence of forestlands (i.e. the distance between the resources to the processing centres or demand points), therefore, the planning system does not offer an opportunity for giving up one interest group what they want in some cases and another interest group what they want in others. Explicitly recognising the multiple spatial option might give an entire new scope for making trade-offs. The real world problem would determine that forestlands would be allocated to the nearest processing centres or demand points for the higher priority of the management regime.

The third aspect is species distribution. This aspect becomes important when implementation occurs. The forestland model allows to explore various feasible solutions. Tables 4.11.A, 4.11.B, 4.11.C show the forestland allocation solutions by species under cases 1, 2, and 3. For example, under objective 6 (max the readiness of plantation arrangement) with MINMAX equal weights "1" formulation, E. deglupta was the main species (955 000 ha, 963 000 ha, and 559 000 ha for cases 1, 2, and 3 respectively). This has two other significant implications namely (i) in the strategic direction of what species combination to set up in a particular locality or region; and (ii) in strategic planning for pest or disease control program what happens 'if' an unexpected disease occurs and destroys most of the plantation establishment; it would be more severe if a single species or lesser number of species had been selected.

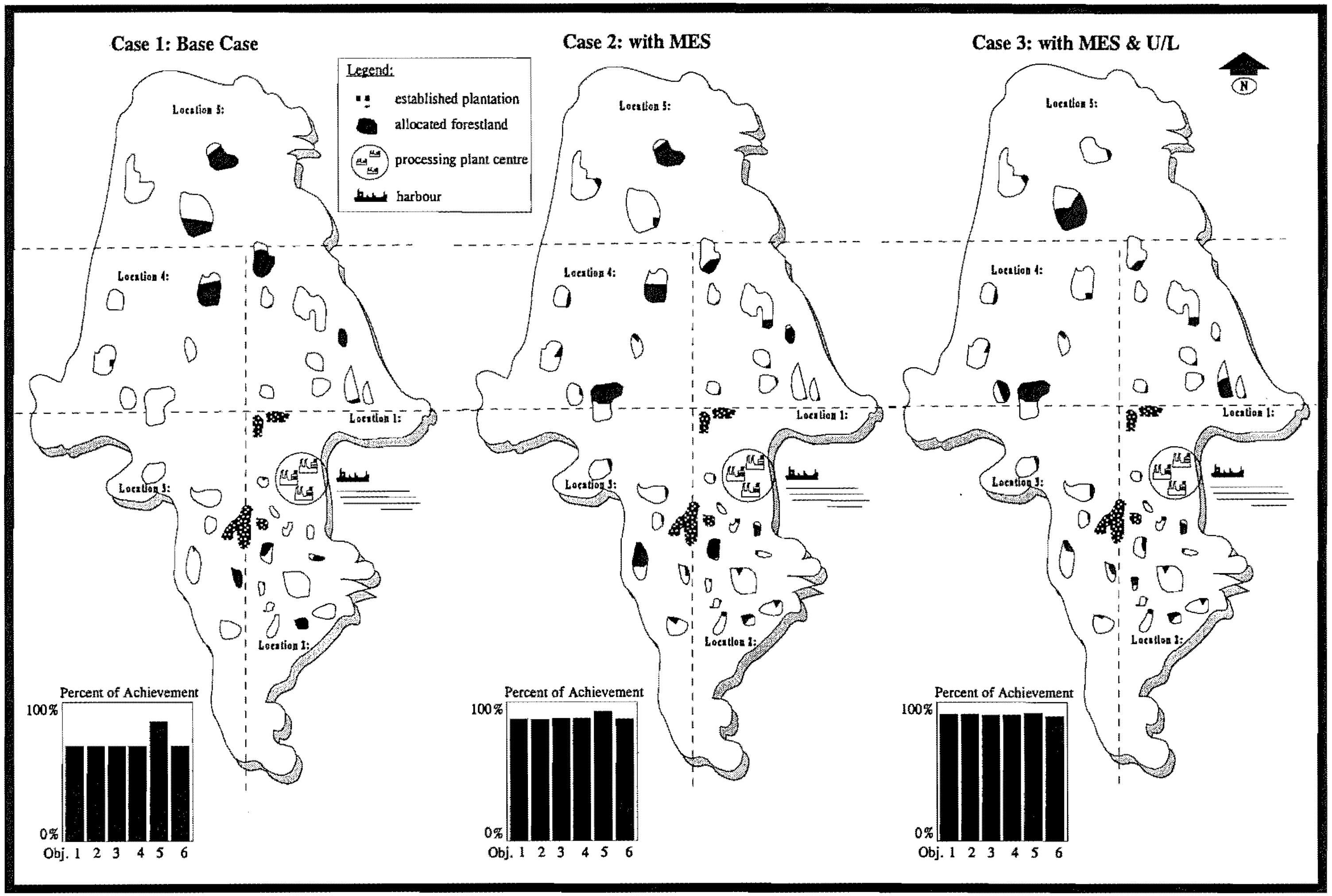


Figure 5.2. Forestland Allocation Model Solutions under Three different Assumptions: MINMAX Formulation

The last aspect to be considered is the plantation size distribution. This aspect relates to the ownership distribution. The decision maker is able to control the incoming proposed applications for industrial forest plantations in order to provide a fair balance of opportunities among stakeholders which can be private or state-owned companies or locals. In other words, this opens up the discussion to what might be an optimal basic structure for industrial forest plantation as has been suggested by Gleason (1987). In this case study, discussion is assumed to be among the decision makers which would maintain some diversity in size amongst the industrial forest plantation sub-sector.

Further implications for this forest allocation problem are that this planning system:

a. allows control over the forestland ownership pattern through different types of ownership (Table 5.2);

Table 5.2. **Different Types of Plantations**

Size	Owner	Integration
small (s_1)	local (o_1)	vertical (i_1)
medium (s_2)	domestic (o_2)	horizontal (i_2)
large (s_3)	foreign (o_3)	

b. allows one to transfer or balance the overall forest resources including natural forest resources. This situation cannot be separated because both natural and plantation forests are actually located side by side and inter-related each other in terms of their spatial patterns. This situation would occur when large wood-based companies (i.e. s_3 and i_2 related to Table 5.2) own forestlands or plantations which are essential to their success (O'Laughlin and Ellefson, 1982). In addition, these companies' strategies which need forestland base are:

- to assure wood supply for their highly capital-intensive processing plants;
- forestlands provide guarantee against short-term period fluctuations, and;
- to provide low-risk of investment (O'Laughin and Ellefson, 1982; Duerr et al., 1979).

In Indonesia, there are large reforestation incentives available which reduces the up front at risk capital. This is covered more fully in c below.

c. allows policy makers to evaluate and monitor how and in what way those new entrants and/or extended traditional companies implement their deliberated compromise plans over time. This is especially important during the initial 5-year planting or establishment of those industrial forest plantations. This monitoring of outputs would have further effects on:

- the nature of financial incentives from the government, cq. Ministry of Forestry of a 32.5 per cent of the total financial requirement would be supported from reforestation fund with 'zero-interest' consideration (or DR) in Ministerial decrees (No.421/Kpts-II/1990 and No.931/KMK.013/1990 for DR requirements; No.19/Kpts-II/1991 and No.752/Kpts-II/1990 for DR distributions for forest state-owned companies and others; No.100/Kpts-II/1993 for DR distributions for governmental investments in industrial forest plantations), and;

- the companies' future forestland strategies, in this case, if they could not manage their existing resources intensively, therefore, they might be classified as non-productive management and would be needed to be supported technically for quite some periods of time (from the Ministry of Forestry) to re-evaluate their existing management strategy and to provide some technical and operational discussion and advise. Further action would be taken on the basis of, for example, delaying of their future extended forestland proposals.

Decisions must be made as close to the situation as possible, with respect to local needs (in this case, for example, in location 1 for production and protection purposes WPPC, IGT and PP respectively), and be consistent with the regional direction. Furthermore, there should be public participation in the local forest decision making process which is integral to ensure that all forest resource values and users are properly taken into account in forest management.

3. The model structure in this study was developed mostly with spreadsheet-based analytical capability. Such systems can now handle big problems even beyond the 100 000 variables and 32 000 constraints (Anonymous, 1995).

   In addition, OR/MS was the central application in this planning system, to allow transparency and avoid other inherently hidden further difficulties. It is important that its contribution to economic and social development should be paid more attention (Papageorgiou, 1990).

There are other regional pressures and objectives, particularly in terms of economic growth, balanced land-use, and employment to be considered. Increasingly, the objectives of sound forestland protection (against shifting cultivation) are being seen to conflict with the aim of preserving roading networks, as forestland production expands. Conversely, restricting forestland production development conflicts with concerns for better future environmental gains and concerns for better utilisation of poorer forestland. Therefore, the regional development targets are certainly consistent with some regional objectives. They can be strengthened through arrangement of planting patterns and economic growth through long-term wood processing.

Forestland allocation model outputs demonstrate some reconciliations such as:

(i) prior possible discussion over setting deliberated targets and options;
(ii) scope for plantation development to occur without conflicting with regional or locational objectives of protecting the poorer forestland.

However, by not describing the nature or the mechanism of the connection between land suitability and actual plantation patterns, the model does not apparently indicate the adjustment of the targets with other regional objectives.

Similarly, without some identification of foreseen plantation development patterns, the regional impacts implicit in the targets cannot be known except in general terms by the appropriate authorities, and the nature and extent of their consensus or conflict with local objectives is difficult to comprehend.

It is these exclusions which determine that although targets have the potential to be adjusted in line with regional objectives, in some important aspects they are not specifically so adjusted.

Discussion of adjustable targets without a transparent mechanism for providing such coordination could induce conflict between forestry and other regional needs, when there is no necessity for any conflict.

5.2.4. **Optimisation-Simulation Linkage**

The fourth step is the linkage between optimisation and simulation models which provides detailed planning opportunities so that decision makers and stakeholders may gain insights before any consensus decisions need to be finally made. Linking LP solutions and simulation planning variations is possible in complex industrial forest plantation development situations and offers more useful, realistic and flexible solutions than either tool alone.

This step is an important support in the selection of industrial forest plantation development plans to evaluate further options among crop type options to meet an array of forest management objectives and goals in regional and sub regional analysis (in this study: locations 1, 2, 3, 4, and 5; see Figure 3.3).

Two existing forest estate models, i.e. RMS-2020 (simulator) and FOLPI (optimisation) were utilised in this study. The intention was to interface these models' capabilities and flexibilities in order to depict regional forestland as it evolves through time in response to technical, operational, financial and other considerations. These two models provide estimates of non pulp and pulp log production required to achieve selected goals.

Without the information provided by the linkage between optimisation and simulation models it would be impractical to simulate enough development options to determine with rational assurance that optimal or near optimal solutions for the options have been established.

Several factors are considered for this linkage that both models:

1. generate solutions that are valid with certain technical advantages and limitations. These are shown in Table 3.6;

2. do not develop implementable plans but can generate consequences which can be used to develop implementable plans.

3. allow for adjustments to specific situations. For example, Figures 5.3, 5.4, and 5.5 show the volume cut comparison for crop types 4, 5, 6, 7, and 8. Volume cut levels have been adjusted in simulation runs under selected target rotations based on results from optimisation. These figures are summarised by Figure 5.6 (for all crop types) and Figure 5.7 (for all crop types by log assortment). Major implications of these level of harvests (especially with further wood supply by different log assortments) are:

    - regional self-sufficiency in wood supply and demand, or;
    - regional surplus in wood supply and demand.

    These two achievements should always be recognised, where there are different log assortments of which may be preferred from a regional or local source to ensure their long-term availability in all situations .

    Figure 5.7 shows the log grade volume cut levels by simulation outputs. Figure 5.8 shows the GIS basic illustration for optimisation solutions for non pulp and pulp logs production for selected crop types under case 4 (constrained optimisation model). Technical investigation such as volume cut and area by given time is able to be conducted.

4 consequences can help evaluate specific alternatives not recognised in both models, for example, future legal aspects of the forestlands. But these aspects might be presented in such a way that being represented in the models. Minimising environmental degradation can be done by minimising total area size for clear cutting (harvesting strategies);

5. are utilised in a one-way link from optimisation and simulation and not in a two-way link. This is because desired or preferred solutions which have been derived from simulation based on the optimal solutions can be categorised as more implementable plans than simulation solutions being recalculated back to optimisation. Recalculation back to optimisation might derive non optimal solutions. It should be noted that the planning goal (in this case for planting, harvesting, forestland transferring, and replanting operations) is *to obtain a general understanding of where we are going and where we can go* (Rose, 1984).

The simulator itself has enabled study of the resource characteristics and management options to be modelled and compared with reality. The analysis allows the strategic planning options to be recommended.

- Further analysis has been conducted to ensure the robustness of the best management strategy. The whole process of managing the regional industrial forest plantation,

mainly aspects of strategic planning, should be adjusted to suit local conditions such as:
(i) for the whole region (regional or provincial analysis), and;
(ii) sub-regional analysis (in this case kabupaten),and/or;
(iii) single forest company.

Those local conditions incorporate with the management objectives matching them more readily with what is applicable in the field. For example:

- the crop type requirement should be extended to keep pace with the field situation to represent more closely and reliably the existing resources;

- a regular inventory programme (which is recommend as an on-going and joint programme among forest owners) needs to be encouraged in order to get more accurate field data to allow the entire plans to be reviewed, particularly production forecasts;

- a better record system broken down into different log assortments around time of final harvesting is needed to describe log type proportions better.

- it is essentially important to choose the most suitable rotation age on the basis of both the quantity and quality of financial maturity together with the sustained yield that can be maintained.

- in order to manage the whole resource under intensive forest management, the tactical and operational planners should choose to harvest at an age that corresponds to the highest financial maturity subject to a regulated yield which takes into account risk. The social and environmental factors have explicitly already been taken into account in the MES and forestland allocation models.

- the management should also develop an extended marketing strategy so as to utilise (if) the surplus log (or roundwood) production available between the planning horizon effectively; whether the other nearer regions such as South Kalimantan, Central Kalimantan, South Sulawesi or even Java can be included in the analysis.

5.2.5. **GIS**

The fifth step GIS, was utilised to enhance the preferred solutions, information, and appearance. This system can provide balance in decision-making by providing a flexible and understandable evaluation tool to all interest groups (see Figure 5.8 for illustration).

Figure 5.3. Volume Cut Comparison
(Crop Types 4 and 5)

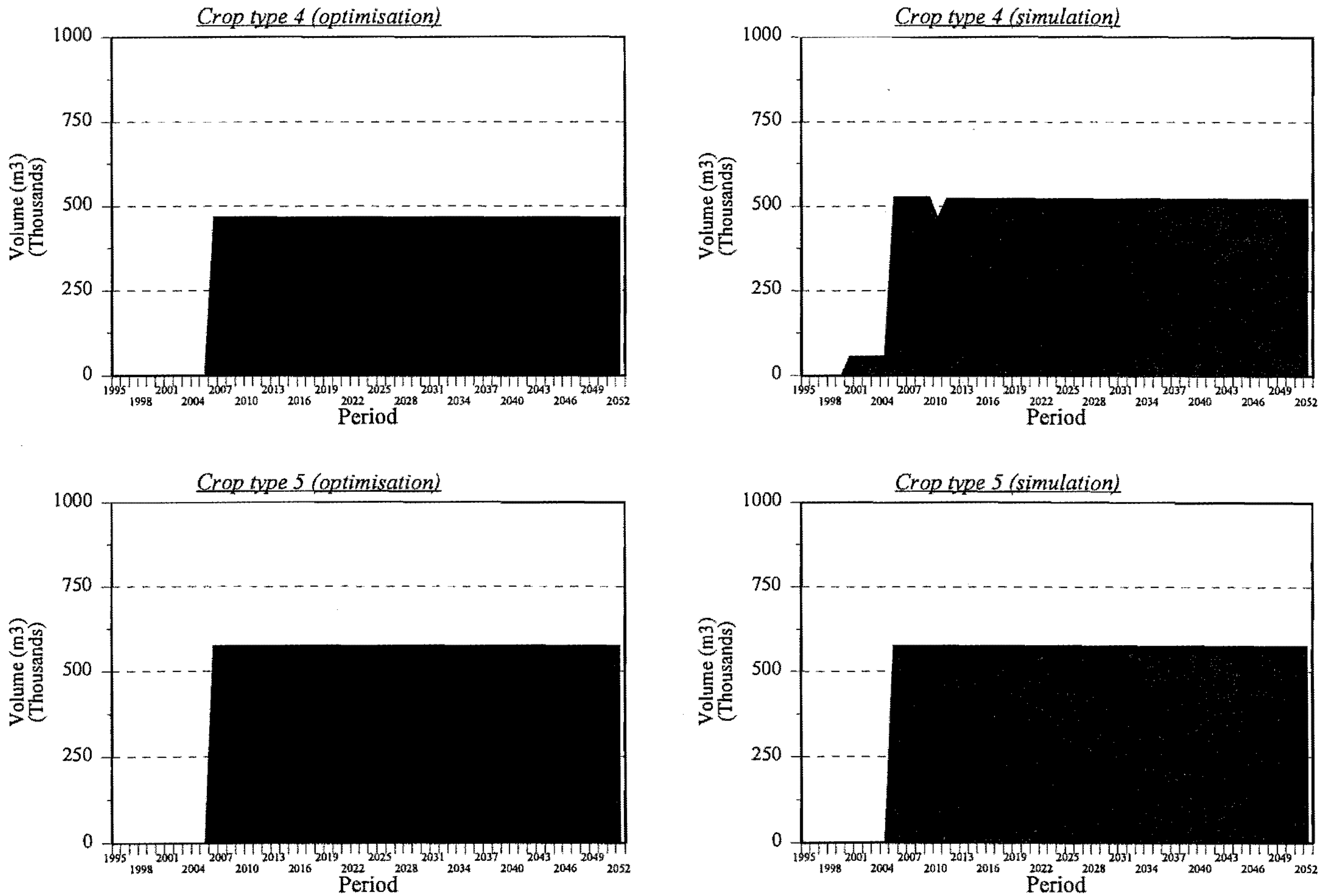


Figure 5.4. Volume Cut Comparison
(Crop Type 6)

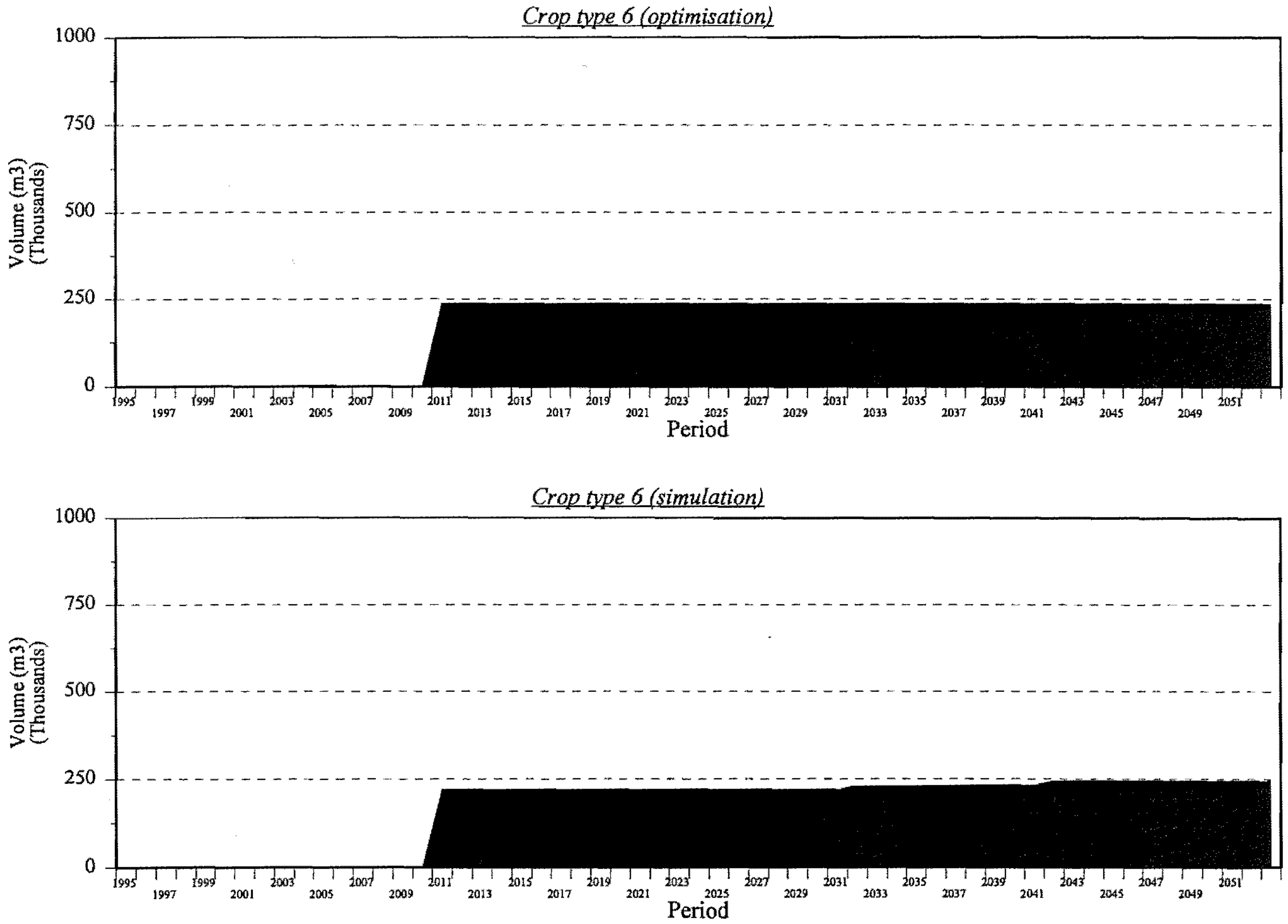


Figure 5.5. Volume Cut Comparison
(Crop Types 7 and 8)

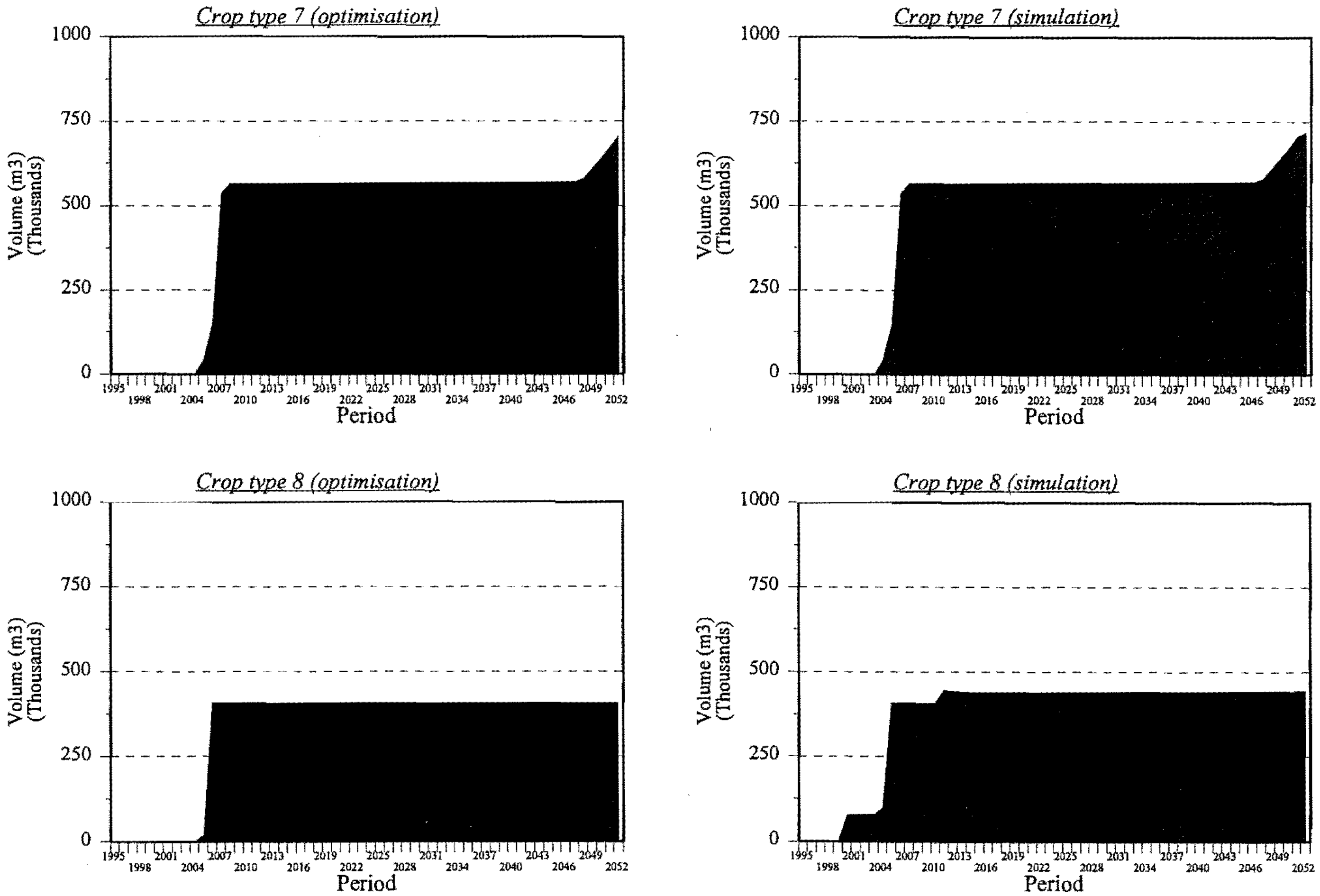


Figure 5.6. Volume Cut Comparison
(All Crop Types by Log Assortment)

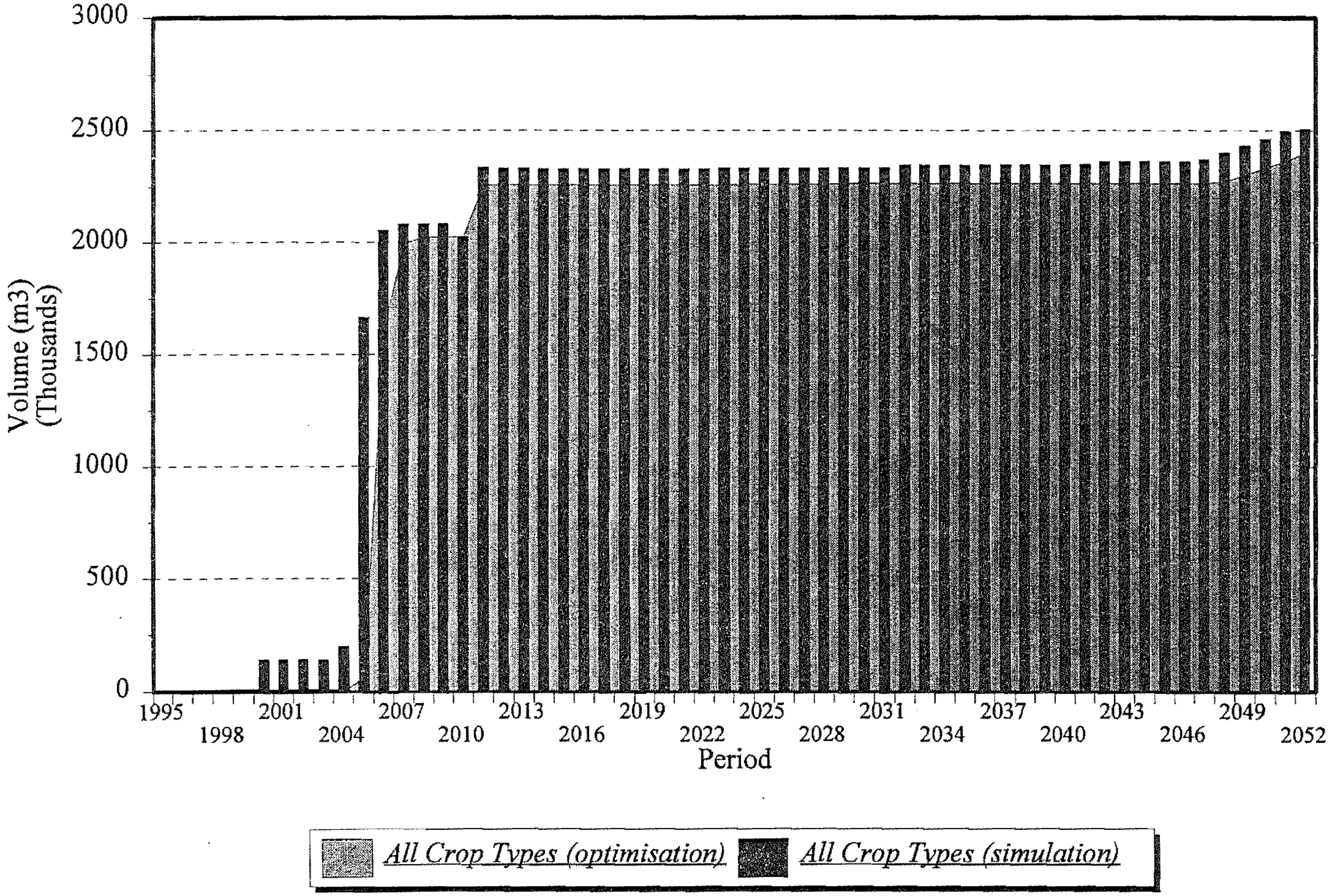
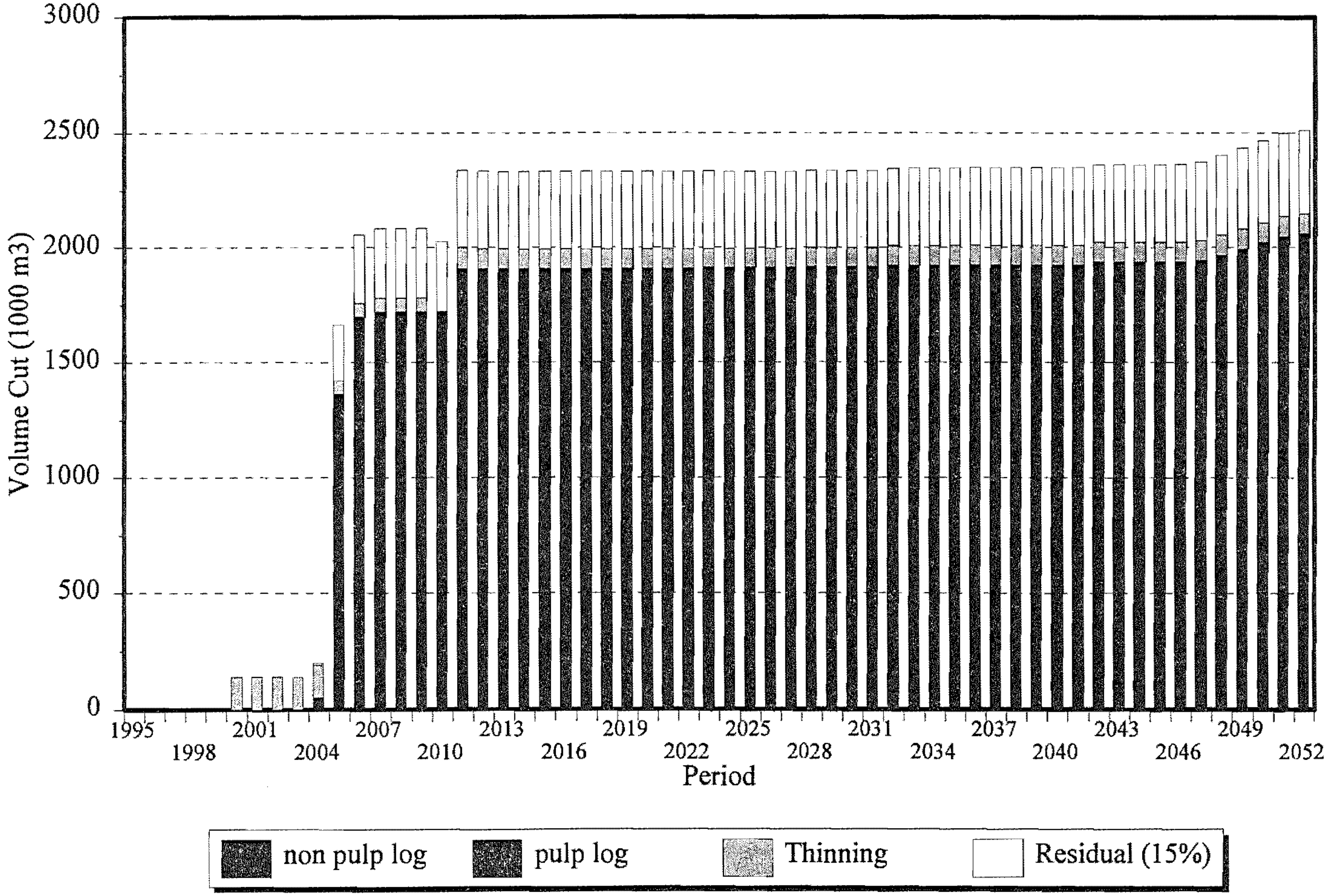


Figure 5.7. Volume Cut by Simulation
(All Crop Types by Log Assortment)



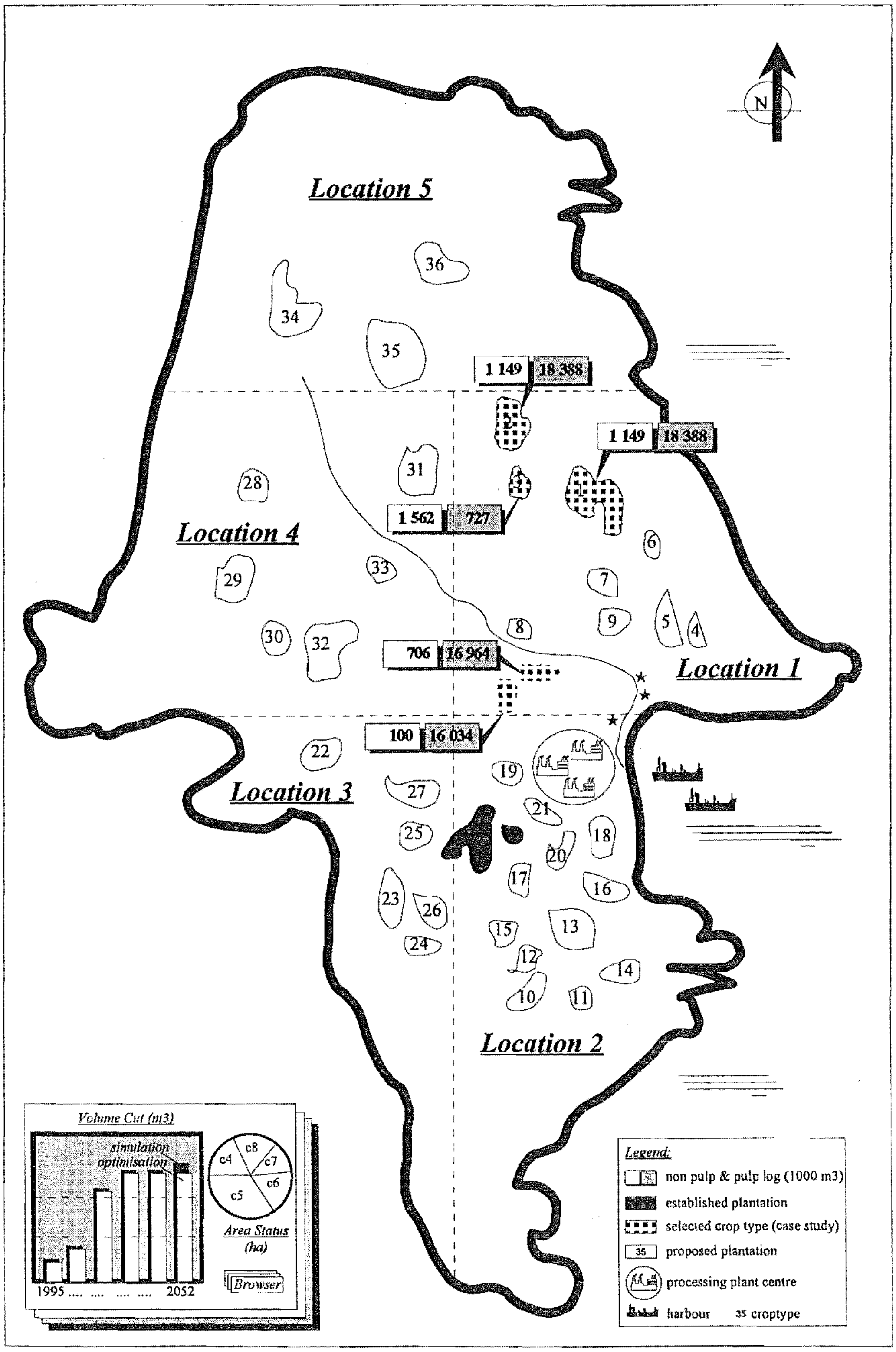


Figure 5.8. GIS Basic Illustration for Optimisation Solutions for Non Pulp and Pulp Logs Production for Selected Crop Types *(enhanced by HGW)*

The utility within this system is its ability to be an interactive and visual requesting system or to preview the visual trade-offs among different objectives. In the discussion session, there would be a dissimilar realisation between the discussion (or the decision makers and stakeholders) interest inherent in the trade-offs and their interest inherent in individual objective functions. It would depend on the situation, if in this discussion where they are explicitly focusing in the trade-offs, there would be a possibility for trying to find out what the interest groups opinion is on such a set of trade-offs. For example, if the consensus focuses in different purposes for the whole forestland case study, the implications would be in the distributions of the crop types, management regimes, and the species.

In terms of all these implications, the stakeholders who were not formally involved in the analysis can now be involved and clearly see the assumptions. This might raise the level of debate and awareness about what is going on and where the discussion is going to be, and later this would lead to some modification and improvement in the decision when it is finally taken. Figure 3.1 shows the detail of the decision framework.

5.2.6. **Implementation and Monitoring**

The sixth step is implementation and monitoring: as several local industrial forest plantation development plans are implemented, performance is monitored and an evaluation of the effectiveness of management objectives is undertaken. This monitoring process constructs a cycle of learning and adaptation to new information (see Figure 3.4).

This monitoring process also observes changes in the crop type spatial pattern (including for forestland conversion to non forest uses), new processing plants (more forestland allocation of a particular size), and inter-regional wood supply (from wood surplus to deficit regions). Two directions from this monitoring process are:

(i) providing updated information in order to modify goals or spatial interactions, and;
(ii) supporting the on-going implementation process.

Planning and implementation of this plantation development must emphasise flexibility and adaptation (Kanowski et al., 1992). Its flexibility and adaptation can be set up in terms of:

(i) plantation finance, for example, by allowing government funding to subsidise any crop type establishment until those plantations can be financially supported by themselves (the first harvesting schedule) which is vital that this have to be achieved. Therefore, the MES model solutions promote selected crop type options, and;
(ii) Investment in plantations complement, rather than substitute for, investments in the conservation or protection (non production).

There are three major concerns with respect to the planning process of regional industrial plantation development:

(i) criticism of the criteria, numerical and spatial analysis procedures and tools which are used during the early phase of regional industrial plantation development;
(ii) reaction to the first concern, i.e. the need to search for simpler, more user-friendly analysis tools, and;
(iii) integrated analysis, which are compatible with past or current other related planning tools.

This planning system offers solutions to the above three major concerns for effective decision-making, namely, starting point and transparent quantitative assessment. Addressing these two concerns assists in resolving conflict in industrial forest plantation development, making such development more feasible and applicable, and tries to fill the gap with appropriate methodology. This methodology should be able to assist in resolving intra-group conflicts.

Then, this in system would allow not only playing its role as a monitoring function but also as a control function over the company's plans and the program of the industrial forest plantation tactics and operations in a given region.

This planning system helps regional industrial forest plantation planners improve their analytical capabilities. It might be an establishment of a vehicle for communicating with other or among interested groups and the public in forestry development (Hosking and Bignell, 1984). Solving the above concerns it requires the development of a set of criteria which will determine when and if the concern is resolved. The two identified following criteria are general and can be modified.

1. Using spreadsheet-based models in forest planning, implementation and monitoring is simple and easy to apply. This also relates to the model's design so as to capture management realism in size and complexity for investment decisions.

2. The planning systems analysis provides assistance in understanding the linkages that need to be made in analysing data sets to achieve deliberated desired solutions.

On the other hand, this system would confront practical constraints to interpretation of solutions from realistically large regional planning problems by practising industrial forest plantation managers. These problems have been pointed out in the New Zealand environment which is also valid for other countries as well (Whyte, 1988). Therefore, direct access to supporting models for planning systems and collaboration among researchers and practitioners should be encouraged. These practical and important issues would reduce similar unwanted outputs, for example, policies towards early establishment of natural forest concessions where the size of those concessions varies (average size is approximately 98 000 ha) and most importantly concession size cannot be easily policed whether by regional forest officers in insuring attachment to regulations by concessionaires or by the concessionaires in preventing illegal cut by poachers (Reppeto and Gillis, 1988).

This planning system does not contain any political or other kinds of direction in which decision makers need to straighten their own minds out (Leslie[1], *pers. comm*). Of course, this is against one theoretical aspect of what the decision makers have to convince others of the correctness of their decisions (Keeney and Raiffa, 1976). In addition, decisions chosen in the public domain are definitively political commitments which are worked out between several interested groups - individuals who represent interest groups or different viewpoints. Ultimately, the analyst's role in the decision making mechanism is to help some technical discussions which then improve the quality of strategic decision-making.

[1] (1995).

Chapter 6. Summary and Conclusions

6.1. Summary

Regional resource planning and decision-making for industrial forest plantation development increasingly involves participation of the public. The theoretical framework outlined here provides a basis for analysing conflict between and within groups (e.g. decision makers, stakeholders, experts and analysts), including people often ignored or left out of the communicative aspects of planning. Motivation to maximise or minimise the degree to which those groups can satisfy their individual objectives should involve recognition of outcomes arrived at in a consensus decision-making environment. In other words, it assumes that groups want to know and want others to know the implications of their positions (which is not always the case but would be an explicitly stated pre-requisite).

A substantial part of the multi-criteria decision making literature is more or less concerned implicitly with the support of decision making where several often conflicting interests are involved. In essence, many MODM texts are vague in their interpretation of 'the decision maker' and in many instances 'the decision maker' has, moreover, actually been a group of individuals.

This study examines possible formal multi-criteria analysis for integrated planning mechanisms relating to industrial forest plantation development at a regional level. Its main objective was to develop a methodology for analysing strategic options for industrial forest plantations that can construct the essence of seeking consensus through effecting trade-offs between conflicting objectives and for evaluating derived options in terms of spatial and transportation consequences or considerations. This methodology can be used by any DM body or individual in order to overcome the above issues.

Other aims were:

- to develop a model which can derive minimum profitable size for any given forest plantation management regimes and species;
- to demonstrate how a consensus-seeking mechanism and integrated planning framework can be set up for modelling regional planning problem, and;
- to test the feasibility of utilising the chosen framework in one specific location for a forest plantation planning problem.

Such an integrated planning system should be robust, capable of being utilised to generate compromise and feasible plans for diverse locations, management regimes, species options and trade-offs. It should also be capable of characterising the main planning problems in choosing plantation regimes in response to a consensus changing decision mechanism and market environment.

The planning problem is different for the private-sector compared to the public-sector, because of apparently fundamental differences in the composition of their decision makers, but both kinds of situations have problems that are exacerbated by inadequate communication. The need to develop a quantitative approach to solving this kind of problem is important.

A technical framework for describing industrial forest plantation options quantitatively was developed through six steps, i.e.:

Step 1: as much as available data and information required for developing and utilising planning models, were collected, sorted and supplied as inputs.

Step 2: MES spreadsheet-based models were run for data relating to various species and under different management regimes.

Step 3: forestland allocation, a spreadsheet-based MODM model, was run to derive several industrial forest plantation development options for six different objectives:

objective 1:	to maximise non pulp log production	(000 m^3)
objective 2:	to maximise pulp log production	(000 m^3)
objective 3:	to maximise soil protection	(util)
objective 4:	to maximise subsistence	(util)
objective 5:	to maximise revenue from the forestland for the organisation	($000)
objective 6:	to maximise the readiness of the plantation	(util)

Discussions and communication with and between all the interested groups (stakeholders as well) can begin after completing this step.

Step 4: crop type allocations were made in anticipation of spatial consequences of model outputs which could then be utilised in linking LP and simulation models:

a. optimisation (LP) models were solved in order to derive several solutions to meet constructed objectives;

b. simulation models were run in order to adjust long-term preferred solutions in terms of log assortments, financial structures, and other considerations not included formally as constraints in (a).

Step 5: a spatial database (in GIS) was generated from simulation model outputs which can then be categorised as:

a. solutions which need further modifications to or refinements of objectives and spatial interactions; or

b. deliberated preferred solutions recommended as final development options for industrial forest plantation;

Step 6: implementation and monitoring of deliberated solutions.

The case study area chosen is located in East Kalimantan, Indonesia, a region which has been playing an important role in the forestry sector at both regional and national levels. A sketch map of the region was drawn to show crop type, each of which represents some function of location, management regime and species (Figures 3.3 and 5.8).

The decisions to be made involve forestland allocation from each proposed crop type among five locations, and four selected management regimes, namely:

1. WPPC (Watershed Part Protection Commercial)
2. HTIT (Industrial Forest Plantation-Transmigration)
3. IGT (Industrial Grade Timber)
4. PP (Pulp Plantation)

Three promising species for each management regime were selected. Thirty six variables were selected and defined to measure the total amount of forestland allocated to each of four selected management regimes.

The first modelling, with a MES spreadsheet-based model, was run to obtain profitable plantation sizes by using financial criteria such as IRR. Then, those outputs were attached to the forestland model as area constraints. This model was developed by applying MINMAX and MINSUM goal programming formulations and using XA as the linear programming solver. Forestland model runs were set under different lower and upper future market demand levels for different log types (non pulp log and pulp log) and under different weights for all six distinct objectives. The ceiling for forestland availability was 2.13 million ha.

Next, several crop types in a specific location were chosen for demonstrating the linking between optimisation and simulation models and for deriving deliberated preferred solutions. The framework and results at this stage are only preliminary, because some data are still incomplete and unrefined. This study is, therefore, as a description of methodology and an indication of the nature of desirable results rather than as a policy recommendation. Furthermore, the framework does not supply answers to the regional planning problem but rather, it does provide as a constructive tool for combining information and considerations relating to the ecological, economic and social considerations in regard to the location of industrial forest plantations in East Kalimantan to be used in deriving answers.

In principle, the framework could become multi-temporal by creating each variable in time-dependent fashion. Simplicity and clarity are essential characteristics of a strategic planning model to facilitate a communicative decision-making process, structured in this case as a general integrated deliberation of planting, harvesting, product manufacturing and marketing strategies. Furthermore, the merit of its process will ultimately determine the implementation of the framework consequences and thus the success or failure of the framework.

6.2. **Conclusions**

From the analyses conducted and from preliminary outputs (as setout in the foregoing discussion) of the research, the following conclusions can be made:

1. Regional wood supply planning to meet the demands of wood processing plants and other markets is one important component of the establishment of industrial forest plantations that needs to be addressed. About 2.13 million ha in East Kalimantan are earmarked for industrial forest plantation development, for which several crucial spatial constraints to achieving sustainable land management need to be recognised before commencing. The combination of physical, social and economic constraints to sustainable forestland management in the region are not yet technically supported and documented. Technical assistance is conclusively required to alter forestland allocation for the next 30-40 years. This study has provided a step in this specific direction by providing a planning framework for regional industrial forest plantation development.

   The planning system or models developed combine all the multiple objectives and interests of all stakeholders in an effective and operationally practical way which is also quantitatively flexible.

2. As the development of industrial forest plantations often produces conflict in use of resources, it becomes a public sector problem, for which multi-criteria analysis is recommended. A conceptual framework of regional plantation development has been generated, its own characteristics confirmed through discussion, where decision makers and stakeholders are encouraged to contribute to the planning process. In other words, the proposed framework and solutions recognise that the planning process is a consensus-searching mechanism.

3. Several potential advantages associated with a multi-criteria decision-making approach that involves all stakeholder participation to plantation development planning have been identified. They include the following facets.

   3.1. Developing and promoting an intellectual, economic, and technological basis for analysis of integrated forest management systems and optimal use of tropical plantation forests, should take into consideration multiple, tangible and intangible benefits. Once poor options or alternatives have been withdrawn, analysts and experts could allow any one of a wide variety of negotiating systems to be introduced and utilised among the planning participants while still comprehending in a reasonably positive way that what was to be resolved would be acceptable.

   3.2. Contributing a more broad-minded regional strategic planning process, after the pertinent decision makers and stakeholders have established the management and monitoring plans and communicated on them.

3.3. Encouraging fuller participation of not only local institutions but also experts and analysts in the development and implementation of planned plantations.

3.4. Encouraging and promoting reviews of the regional forestry sector which pay full attention to plantation forest management, to the influence of other economic sectors and environmental considerations, while recognising that these preferred plans should rely also on a preliminary market forecast of the demands and clear judgment of what management regimes and species selections need to be accomplished and where these plantations are required to be distributed.

4. A case study to determine minimum economic area for four main industrial forest plantation regimes was undertaken by examining three selected and recommended species options. Preliminary minimum economic area calculations for the chosen management regimes are shown in Table 4.3. These numbers reflect net planting areas and are based on spreadsheet calculations which can then be combined with the forestland allocation spreadsheet-based model.

5. The forestland model derived in this study is a spreadsheet-based goal programming model which uses XA as the linear programming solver in such away that it is able to offer the flexibility of spreadsheet application. Model structures were based on the MINMAX and MINSUM formulations, which generate the 'best' compromise solution corresponding to rational weights applied to the various objective functions. It eliminates the need for the DM to scan a set of efficient solutions, which are likely to be of sizeable dimensions in real life and which present an enormous task. The model solutions vary depending on the proposed weights applied and contribute, therefore, consistent insights into the best forestland allocation consensus to accept as the regional development options for industrial forest plantation (Tables 4.4, 4.5, 4.6, 4.7, 4.8, 4.9 and 4.10).

6. Linking LP solutions and simulation planning variations is possible in complex industrial forest plantation development situations and offers more useful, realistic and flexible solutions than either alone. Deliberated preferred solutions are derived from the linkage between LP and simulation. A two-way linking facility was developed by utilising spreadsheet-based macros; i.e. the first way is data transfer from simulation to optimisation, then the second way is solution transfer from optimisation back to simulation.

   A major part of the research reported here was to develop a way of transferring data from simulation to LP models and back again automatically. This linkage has several advantages:

   6.1. Theoretical "optimal" LP solutions are usually unrealistic in practical or implementation terms because of administrative problems facing forest management whereas simulation allows one to explore the effect of deviations from the "optimal" LP solutions. Simulation detail also provides broader aggregated indications. If the measures, for example, wood and financial flows, are unsatisfactory, constraints are modified and formed for the LP model utilising, e.g. the future log assortment flow consequences and the trade-offs between them.

6.2. Linking LP solutions and simulation planning variations is possible in complex forest plantation development situations and offers more useful, realistic and flexible solutions than either alone.

6.3. Both models provide further choice in the system approach for strategic planning through an improvement in the quality of consensus decision-making.

7. Final development options for industrial forest plantations at the regional level can then be presented visually through GIS in order to examine other facets of spatial consequences. This technique can be implemented at various earlier decision-making stages as well.

8. Procedures for resolving inherent conflicts in decision-making, such as legal options and rights, are able to be clearly made and worked out before the availability and capabilities of forestlands are assessed.

Chapter 7. Recommendations

The ultimate value of the quantitative information generated in this framework (or methodology) through a case study analysis is its ability to facilitate policy implementation to satisfy decision-makers and stakeholders when making informed choices in fundamental management decisions. Its interactive capability highlights and demonstrates that this planning system offers a fair balance of playing a key role in decision-making process between the decision makers and stakeholders and between the decision makers and analysts or experts in deliberating preferred solutions through consensus and compromise paradigms. The role of this planning system is therefore to intend to complement and to support the existing planning systems by providing a methodology that starts off with differing interests. This study has shown one way of achieving this.

While this study focused on inter group decision making, this planning system could also represent an adequate decision-making framework or methodology in resolving intra group conflicts, for example different management levels within the Ministry of Forestry.

Further specific suggestions for further work follow:

1. In the MES model, the combination of species could be further studied by allowing different species mixtures in terms of financially optimal combinations.

2. The availability of qualified foresters is satisfactory, but more training capacity is needed for industrial forest plantation technician and skilled forestry operators (ADB, 1987). Furthermore, this condition should be reconsidered by the GoI (Ministry of Man-Power). The prototype of the forestland allocation model is able to be extensively structured in terms of adding other typical constraints such as man-power and financial constraints.

3. The planning system could be temporally structured to reflect time detail through the development of the industrial forest plantations.

4. The feasibility of plans developed based on the results from the forestland allocation models proposed in this study would depend on the accuracy both the inventory representing the resource and the growth models used. If this planning tool is to be implemented, the Ministry of Forestry should review its inventory data and growth models to determine if they provide sufficient accuracy for the forestland allocation outputs.

5 The development of GIS modelling would enhance this planning system, as most forest enterprises keep stand and other operating records in digital databases to generate and evaluate the type of analysis required.

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Appendix 3.1. Species Specification for Minimum Economic Size Application (MES)

No.	Cost or Price Items	Unit	Management Regime 1: WPPC			Management Regime 2: HTIT			Management Regime 3: IGT			Management Regime 4: PP			Sources & Notes
			A. falcataria	*C. calothyrsus*	*D. latifolia*	*A. falcataria*	*E. deglupta*	*G. arborea*	*E. deglupta*	*E. urophylla*	*G. arborea*	*A. mangium*	*E. deglupta*	*E. urophylla*	
1	**Nursery**														
	- invest & replacement	Rp.	*>>> assumption: vary proportion to plantation sizes <<<*												Sources:
	- # seedling per ha	#/ha	1,200												1. Aruan (1990).
	- seedling cost per 1000	Rp.000	30	10	30	35	37	30	40	38	38	30	33	35	2. Groome Poyry (1987).
	- seedling cost per ha	Rp./ha	36	12	36	42	44	36	48	46	45	36	40	41	3. Vademecum (1976).
															4. MoF (1993-1995).
2	**Establishment**														
	- invest & replacement	Rp.	*>>> assumption: vary proportion to plantation sizes <<<*												Notes:
	- land rent	Rp/ha	*>>> assumption: zero land opportunity cost <<<*												1. Data were adjusted to update.
	- area survey	Rp/ha	4,129	4,129	4,129	>>>									2. Several hypothetical data were used.
	- demarcation	Rp/ha	2,949	2,949	2,949	>>>									3. Assumptions were set up.
	- land preparation	Rp/ha	330,283	330,283	330,283	>>>									
	- planting	Rp/ha	53,081	58,389	53,081	>>>									
	- beating up	Rp/ha	4,718	5,190	4,718		*>>>costs are assumed to be similar to WPPC costs<<<*								
	- weeding	Rp/ha	27,130	29,843	27,130	>>>									
	- fertiliser	Rp/ha	62,518	62,518	56,266	>>>									
	at year:	year	1	1	1	>>>									
	- pruning: = first	Rp/ha	*>>> assumption: vary proportion to species specification <<<*												
	at year:	year	*>>> assumption: vary proportion to species specification <<<*												
	= second	Rp/ha	0	0	0	>>>									
	at year:	year	0	0	0	>>>									
	- supervision	Rp/ha	25,951	25,951	25,951	>>>									
	- thinning: = first	Rp/ha	5,000	0	5,000	>>>									
	at year:	year	5	0	5		*>>>costs are assumed to be similar to WPPC costs<<<*								
	= second	Rp/ha	0	0	0	>>>									
	at year:	year	0	0	0	>>>									
	- roller	Rp./#	58,979	58,979	58,979	>>>									
3	**Fire and Disease**														
	- equipment	unit/ha	*>>> assumption: vary proportion to plantation sizes <<<*												
	- fire cost	Rp/ha	4,467	4,467	4,467		*>>>costs are assumed to be similar to WPPC costs<<<*								
	- disease cost	Rp/ha	885	885	885		*>>>costs are assumed to be similar to WPPC costs<<<*								
4	**Road**														
	- access roading	Rp./unit size	*>>> assumption: vary proportion to plantation sizes <<<*												
	- access road	Rp./km	32,745	32,745	32,745	>>>									
	- establishment road	Rp./km	22,966	22,966	22,966	>>>									
	- main road	m/ha	15,051	15,051	15,051	>>>									
	- secondary road	m/ha	7,915	7,915	7,915		*>>>costs are assumed to be similar to WPPC costs<<<*								
	- harvest road	Rp./km	177	177	177	>>>									
	- rd maintenance: <= 6-yr	Rp./km	625	625	625	>>>									
	> 6-yr	Rp./km	448	448	448	>>>									
5	**Administration and Overhead**														
	- housing & equipment	Rp./unit size	*>>> assumption: vary proportion to plantation sizes <<<*												
	- office, workshop & etc	Rp./unit size	*>>> assumption: vary proportion to plantation sizes <<<*												
	- overhead & staffing	Rp./unit size	*>>> assumption: vary proportion to plantation sizes <<<*												
	- electricity & water	Rp./unit size	*>>> assumption: vary proportion to plantation sizes <<<*												
	- planning: = 1-year	Rp./1-year	5,000	5,000	5,000		*>>>costs are assumed to be similar to WPPC costs<<<*								
	= 5-year	Rp./5-year	7,500	7,500	7,500	>>>									
6	**Thinning and Harvesting Yields**														
	- thinning: = first	cum/ha	20	0	52	0	0	60	0	0	60	0	0	0	
	at year:	year	5	0	10	0	0	5	0	0	5	0	0	0	
	= second	cum/ha	0	0	0	0	0	0	0	0	0	0	0	0	
	at year:	year	0	0	0	0	0	0	0	0	0	0	0	0	
	- harvesting (final yield)	cum/ha	150	185	165	200	150	200	120	150	200	194	160	150	
	at year:	year	10	10	15	12	12	15	12	12	15	10	12	12	
	- log class 1 non-pulp	%	10.00%	5.00%	20.00%	6.82%	11.89%	14.58%	49.02%	50.00%	33.33%	0.00%	0.00%	5.88%	
	- log class 2 pulp	%	90.00%	95.00%	80.00%	93.18%	88.11%	85.42%	50.98%	50.00%	66.67%	100.00%	100.00%	94.12%	
	- exploitation factor	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
7	**StumpageValue, Price and DR (Reforestation Fund)**														
	- thinning	Rp./cum	10,000	10,000	12,500	0	12,500	10,000	13,750	12,000	10,000	10,000	12,500	12,500	
	- log class 1 non pulp	Rp./cum	72,000	69,000	69,500	72,000	75,500	74,000	87,250	80,000	75,000	68,500	75,500	75,500	
	- log class 2 pulp	Rp./cum	27,500	24,000	34,000	27,500	36,250	26,000	28,000	24,500	24,500	24,000	35,100	36,250	
	- DR: = log	US$/cum	10	10	10	10	10	10	10	10	10	10	10	10	
	= chip	US$/cum	1	1	1	1	1	1	1	1	1	1	1	1	

Appendix 3.2.A. Nursery Cost Schedule for .... ha .... Plantation

Period	Area		Seedling	Investment &	Seedling Production				Sub Total	Assumptions	(%)	Cost	Cost/Unit	Notes
	Planted	Cummulative	Planted	Replacement	*Species1*	*Species2*	*Species3*	Sub Total	Nursery					
	ha	ha	# Seeds	000 Rp.					NZ$1000					
-1										Seedling				*
0										*Species1*				* modified
1										*Species2*				* modified
...										*Species3*				
...										Investment & Replacement				* weighted
...														
28														
Total														
Control														

Table 3.2.B. Establishment and Silviculture Cost Schedule for .... ha .... Plantation

Period	Area Planted	Investment & Replacement	Area Survey	Direct Supervision	Land-Prep	Planting	Beating up	Weeding (once only)	Fertilizer (once only)	Pruning at yr ?	Thinning at yr ?	Sub Total Establh	Assumptions	Unit	Cost/Unit	Notes
	ha	000 Rp.										NZ$1000				
-1													Area Survey	Rp./ha		**
0													Demarcation	Rp./ha		**
1													Land-prep	Rp./ha		* modified
2													Planting	Rp./ha		* modified
...													Beating-up	Rp./ha		* modified
...													Weeding	Rp./ha		* modified
...													Fertilizer	Rp./ha		* modified
...													Pruning	Rp./ha		**
...													Supervision	Rp./ha		* modified
...													Thinning	Rp./ha		
...													- Roller	Rp./#		* million
...													Pruning:	*Species1*	at year	
...														*Species2*	at year	
...														*Species3*	at year	
...																
28													Thinnings:	*Species1*	at year	
Total														*Species2*	at year	
Control														*Species3*	at year	

Appendix 3.2.C. Fire and Disease Control Cost Schedule for .... ha .... Plantation

Period	Area		Equipment	Operating Cost for		Sub Total	Assumptions	Unit	Cost/Unit	Notes
	Planted	Cummulative		Fire	Disease	Fire & Disease				
	ha	ha	000 Rp.			NZ$1000				
-1							Equipment	Unit/ha	weighted	* modified
0							Fire Cost	Rp./ha		* recalculated
1							Disease Cost	Rp./ha		** modified
2										
...							- Equipment includes vehicles and fire towers			
...							- Operating Cost includes maintenance			
...										
...							Reference for cell D26: N25*N2+O25			
28										
Total										
Control										

Appendix 3.2.D. Roading Construction and Maintenance Cost Schedule for .... ha .... Plantation

Period	Area		Access	Establishment	Harvest	Roading	Sub Total	Assumptions	Unit	Cost/Unit	Notes
	Planted	Cummulative	Roading	Roading	Roading	Maintenance	Roading				
	ha	ha	000 Rp.				NZ$1000				
-1								- Access Road	Rp./km		* 10 km modified
0								- Estblh Road	Rp./km		* modified
1								= Main	m/ha		* 7 m/ha modified
2								= Secondary	m/ha		* 22m/ha modified
...								- Harvest Road	Rp./km		** upgraded
...								- Maintenance	Rp./km		* < year 6 modified
...									Rp./km		* > year 6 modified
28											
Total											
Control											

Appendix 3.2.E. Administration and General Cost Schedule for .... ha .... Plantation

Period	Area		Housings &	Office,Workshop	Overhead &	Electricity	Planning	Sub Total	Assumptions	Unit	Cost/Unit	Notes
	Planted	Cummulative	Equipment	& Storage	Staffing	& Water		Administration				
	ha	ha	000 Rp.					NZ$1000			000 Rp.	
-1									Housings	Rp./area		** constant
0									Office etc	Rp./unit		** modified
1									Electricity	Rp./unit		** constant
2									Planning	Rp./1 yr		** constant
...										Rp./5 yrs		** constant
...									Overhead	Rp./ha		*** updated
...									Maintenance	Rp./unit		**
...												
...									- Housing maintenance every 5 years			
...									- Office maintenance every 10 years			
...									- Electricity replacement after 15 years			
...									- Planning: RKT (1 year) and RKL (5 years)			
...												
...									- Staffing:			***modified
28										T = Top Management		
Total										M = Middle Management		
Control										L = Low Management		

Appendix 3.2.F. Thinnings and Harvesting Schedule for .... ha .... Plantation

Period	Area	*Species1*				*Species2*				*Species3*				Total Net		Assumptions	Unit	Unit/ha	Notes
	Planted	Area	Thinning	LC1 Harvest	LC2 Harvest	Area	Thinning	LC1 Harvest	LC2 Harvest	Area	Thinning	LC1 Harvest	LC2 Harvest	Thinning	Harvesting				
	ha	ha	cu.m	cu.m	cu.m	ha	cu.m	cu.m	cu.m	ha	cu.m	cu.m	cu.m	cu.m	cu.m				
-1																Thinnings:			at year:
0																- Species1	cu.m/ha		0
1																- Species2	cu.m/ha		0
2																- Species3	cu.m/ha		0
3																			
...																Final Yields:			
...																- Species1:	cu.m/ha		10
...																- Species2:	cu.m/ha		0
...																- Species3:	cu.m/ha		0
...																Notes: LC1	Log Class1		Non Pulpwood
...																LC2	Log Class2		Pulpwood
...																Exploitation Factor			**
28																- Species1	harvested at age		
Total																- Species2	harvested at age		
Control																- Species3	harvested at age		

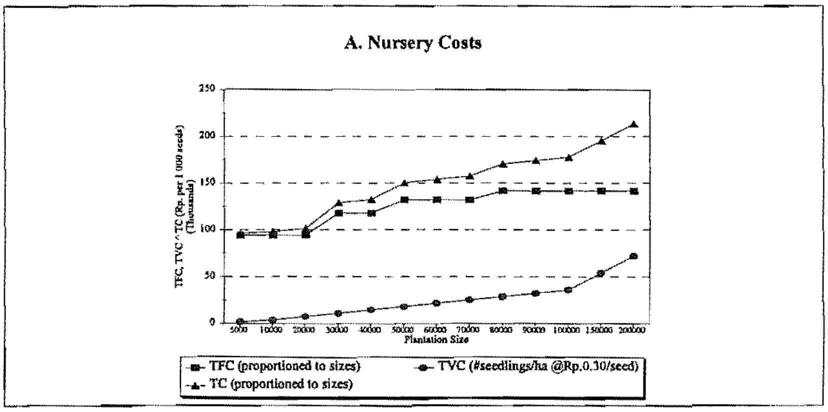
Appendix 3.2.G. Revenue Schedule for .... ha .... Plantation

Period	Area	*Species1*			*Species2*			*Species3*			Total	Total	Assumptions	Species	Unit	#/Unit	Notes
	Planted	Thinning	LC1 Harvest	LC2 Harvest	Thinning	LC1 Harvest	LC2 Harvest	Thinning	LC1 Harvest	LC2 Harvest	Revenue	Net Revenue					
	Ha	cum									000 Rp.	NZ$1000					
-1													**Thinning Yield**	*Species1*	cu.m/ha		*** year ?
0														*Species2*			*** year ?
1														*Species3*			*** year ?
2													**Final Yield:**	*Species1*	cu.m/ha		*** year ?
3														*Species2*			*** year ?
...														*Species3*			
...													Costs:	-Thinnings	Rp./cu.m		* Average
...														- Harvesting	Rp./cu.m		* Average
...														-Transport	Rp./km		* 50 km
...													**Stumpage Value:**				
...													Thinnings:	*Species1*	Rp./cu.m		
...														*Species2*			
...														*Species3*			
...													LC1:	*Species1*	Rp./cu.m		
...														*Species2*			
...														*Species3*			
...													LC2:	*Species1*	Rp./cu.m		
...														*Species2*			
...														*Species3*			
...													Reforestation Fund [1989]:		Rp./cu.m		*** Log
...															Rp./cu.m		*** Chip
...													Exchange Rate:		US $ 1.00 =		
28													Taxable Income:	< Rp.10 million		15.00%	Tax Rate:
Total														Rp.10-50 million		25.00%	
Control														> Rp. 50million		35.00%	

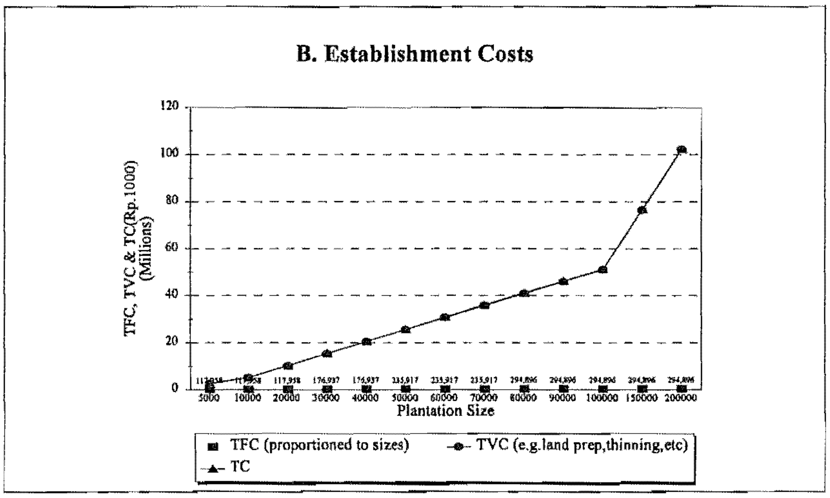
Appendix 3.2.H. Total Costs and Revenues Schedule for .... ha .... Plantation

Period	Nursery	Establishment & Silviculture	Fire & Disease Control	Road Construction & Maintenance	Administration & General	Total Costs	Total Net Revenue	Net Cash Flow	IRR & NPV Calculations	
	NZ$1000									
-1									IRR	
0									NPV	NZ$1000
1									with DR= 0	
2									1%	
3									2%	
...									3%	
...									4%	
...									5%	
...									6%	
...									7%	
...									8%	
...									9%	
...									10%	
...									11%	
...									12%	
...									13%	
...									14%	
28									15%	
Total										
Control									DR [%]	Discount Rate

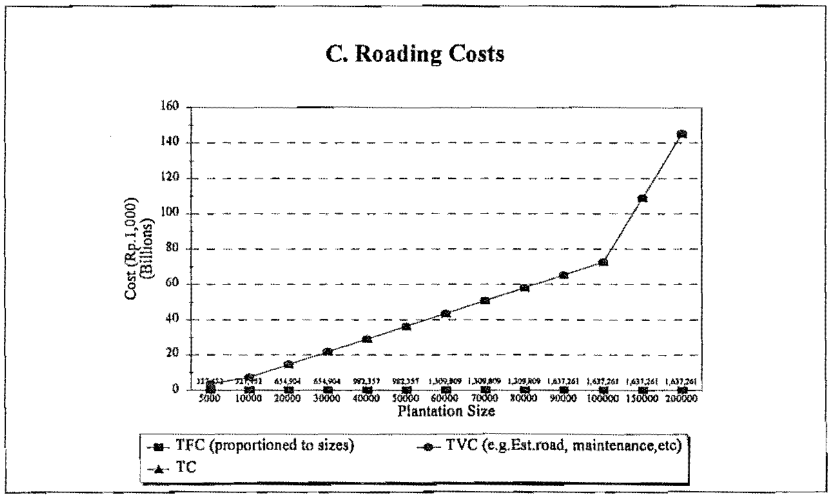
Appendix 3.3. Cost Details and Weights



A. Nursery Costs



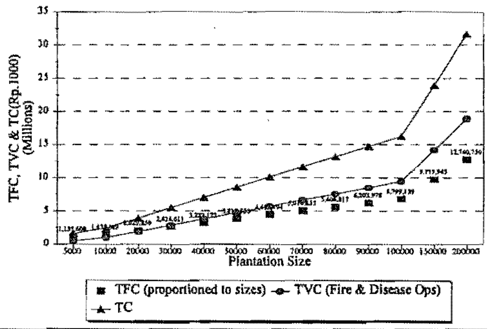
B. Establishment Costs



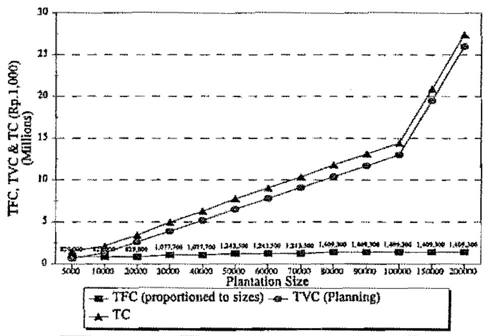
C. Roading Costs

Appendix 3.3. Cost Details and Weights (continued)

D. Fire and Disease Costs



E. Administration and Overhead Costs



Appendix 3.4. Hypothetical Location Distribution

MES: Base Case (000 ha)	Code	Location (000 ha)					
		L1	L2	L3	L4	L5	Sub-total
30	M1S1	260	290	260	300	275	1,110
30	M1S2	250	300	250	300	290	1,100
20	M1S3	300	300	280	305	255	1,185
	Sub-total	305	300	250	305	290	
20	M2S1		280		310		590
20	M2S2		275		310		585
30	M2S3		300		305		605
	Sub-total	0	300	0	315	0	
20	M3S1	355	310	270			935
10	M3S2	360	300	275			935
10	M3S3	330	310	275			915
	Sub Total	365	320	275	0	0	
40	M4S1	375	320				695
40	M4S2	350	300				650
40	M4S3	350	300				650
	Sub-total	350	345	0	0	0	
	Total	565	677	278	320	290	2130

Notes: *no area applicable for given management regimes.*

Appendix 3.5. Technical Recommendations for RMS-2020 Applications

1. **For #471.WB1 and #470.WB1 applications:**
   Command 471 (volume cutting plan) is a better utilisation command than command 470 (area cutting plan) in terms of handling what FOLPI volume cutting plans are. In other words, it provides a quick summary of volumes cut through RMS-2020 in the command utilisation (i.e. practicality and flexibility in application).

2. **For age classes:**
   It is advisable to have single year age classes represented in both models. RMS-2020 provides 60 rows or 60 age classes.

Appendix 3.5.A. List of Commands and Their Usage Employed in RMS-2020

Commands	Usages
40	Combination crop type to form crop type 1, a weighted average for the whole forest.
100	Year of forest description.
101	Regeneration interval between time of harvesting one crop type and fully establishing the next.
105	Attrition effect, to allow the areas of stands which never succeed through to final rotation age to be regenerated.
120	Yield increment (addition and substraction), to adjust in line with future changes in crop regime over time.
129	Relative maturity, the age which are relative to a rotation.
205	Regeneration cost, average for all crop types throughout the forest.
210	Initial costs for a particular crop type. The difference between a crop type's planting cost and regeneration cost is expressed by using sign (+) if the initial cost is higher than average and, by contrast sign (-) if the initial cost is lower than the one of command 205.
212	Land value (per ha).
215	Taxation, \$/\$ of net revenue.
225	Price differentials about the average stumpage wood price. \$/m^3 by crop type, log class and age.
250	Discount rates that form a representative range for analytical purpose.
301	Measure of growing stock, increment and average age; code 1 for listing by crop type and age class; similar to command #stock.
332	NEV, normal exchange value, value of the current management regime if it was managed as a normal one. Command #NEV is also applicable.
333	Present Net Worth of a formula cut to target rotation; command 333, R in which R represents a target rotation age.
335	Allowable cut for a specific target rotation; typically command 335, R is employed.
401	Harvesting operations; generally command #use 0,3 is used to switch on the command 471 for simulating the harvest set out in the logging plan.
471	Clearfell resource plan to specify source of clearfellings in detail less than a specific age by crop type; sign (-) is used prior to a minimum age of clear felling.
480	Planting plan to provide additional area, i.e. new plantings into a forest description and to simplify specification of simulation sequences.
485	Default regeneration plan; to direct regeneration default to crop type of origin, command 486,1 must be used.
910	Read forest description of file name; typically command #get is applied.
915	Save forest description as filename; usually command #save is used.
931	Listing forest description of crop type characteristics; used together with command 940 for error checking before simulation.
934	Listing log class data by crop type.
940	Table listings of specified management plans; to list commands 102, 125, 215, 129, 210, 471, 480 and 486.
950	Land reserve and reconciliations; a simulation default to command 480 planting from reserve; as reserve land for planting, code 1 is applied and so to be command 950,1.
998	End command list segment; to alternate between data entry and command syntax.
999	End job; being used to temporarily truncate a job.

Appendix 3.6. Coefficients for Forestland Allocation Model

Variable	Coefficients for Objective					
	1	2	3	4	5	6
L1M1S1	15	135	9	2	4523	17
L1M1S2	9	176	9	3	4444	12
L1M1S3	33	132	10	2	6641	8
L1M3S1	59	61	5	8	5846	112
L1M3S2	75	75	5	7	6568	107
L1M3S3	67	133	4	7	7543	103
L1M4S1	0	194	2	5	4358	61
L1M4S2	0	160	3	5	5370	56
L1M4S3	9	141	3	5	5431	52
L2M1S1	15	135	9	2	4523	17
L2M1S2	9	176	9	3	4444	12
L2M1S3	33	132	10	2	6641	8
L2M2S1	14	186	7	10	5610	22
L2M2S2	18	132	6	10	5660	17
L2M2S3	29	171	6	9	6396	13
L2M3S1	59	61	5	8	5846	111
L2M3S2	75	75	5	7	6568	106
L2M3S3	67	133	4	7	7543	102
L2M4S1	0	194	2	5	4358	61
L2M4S2	0	160	3	5	5370	56
L2M4S3	9	141	3	5	5431	52
L3M1S1	15	135	9	2	4523	19
L3M1S2	9	176	9	3	4444	14
L3M1S3	33	132	10	2	6641	10
L3M3S1	59	61	5	8	5846	113
L3M3S2	75	75	5	7	6568	108
L3M3S3	67	133	4	7	7543	104
L4M1S1	15	135	9	2	4523	19
L4M1S2	9	176	9	3	4444	14
L4M1S3	33	132	10	2	6641	10
L4M2S1	14	186	7	10	5610	24
L4M2S2	18	132	6	10	5660	19
L4M2S3	29	171	6	9	6396	15
L5M1S1	15	135	9	2	4523	20
L5M1S2	9	176	9	3	4444	15
L5M1S3	33	132	10	2	6641	11

Notes:

Objective 1 *maximise non pulp log production (cum)*

Objective 2 *maximise pulp log production (cum)*

Objective 3 *maximise soil protection (util)*

Objective 4 *maximise subsistence for local community (util)*

Objective 5 *maximise revenue for the organisation (NZ$000)*

Objective 6 *maximise the arrangement readiness of the plantation (util)*

Utility Scale:

+1: undesirable outcome or mpact

....

+5: neutral outcome or impact

....

+10: most desirable outcome or impact

Appendix 5.1. Detailed Volume Cuts for Optimisation and Simulation Runs

Optimisation Crop Type						Period	*Simulation* Crop Types					
4	5	6	7	8	Total		4	5	6	7	8	Total
Volume Cut (m3)							Volume Cut (m3)					
0	0	0	0	0	0	1995	0	0	0	0	0	0
0	0	0	0	0	0	1996	0	0	0	0	0	0
0	0	0	0	0	0	1997	0	0	0	0	0	0
0	0	0	0	0	0	1998	0	0	0	0	0	0
0	0	0	0	0	0	1999	0	0	0	0	1000	1000
0	0	0	0	0	0	2000	60000	0	0	0	80000	140000
0	0	0	0	0	0	2001	60000	0	0	0	80000	140000
0	0	0	0	0	0	2002	60000	0	0	0	80000	140000
0	0	0	0	0	0	2003	60000	0	0	0	80000	140000
0	0	0	0	0	0	2004	60000	0	0	42000	98000	200000
0	0	0	42065	19929	61994	2005	529000	578000	0	149000	409000	1665000
469091	578182	0	149111	408667	1605051	2006	529000	578000	0	540000	409000	2056000
469091	578182	0	540297	408667	1996236	2007	529000	578000	0	568000	409000	2084000
469091	578182	0	567576	408667	2023515	2008	529000	578000	0	568000	409000	2084000
469091	578182	0	567576	408667	2023516	2009	529000	578000	0	568000	409000	2084000
469091	578182	0	567576	408667	2023516	2010	469000	578000	0	568000	410000	2025000
469091	578182	236250	567576	408667	2259766	2011	524000	578000	220000	568000	447000	2337000
469091	578182	236250	567576	408667	2259766	2012	524000	578000	220000	568000	443000	2333000
469091	578182	236250	567576	408667	2259765	2013	524000	578000	220000	568000	442000	2332000
469091	578182	236250	567576	408667	2259766	2014	524000	578000	220000	568000	440000	2330000
469091	578182	236250	567576	408667	2259765	2015	524000	578000	220000	568000	440000	2330000
469091	578182	236250	567576	408667	2259766	2016	524000	578000	220000	568000	440000	2330000
469091	578182	236250	567576	408667	2259766	2017	524000	578000	220000	568000	440000	2330000
469091	578182	236250	567576	408667	2259765	2018	524000	578000	220000	568000	440000	2330000
469091	578182	236250	567576	408667	2259765	2019	524000	578000	220000	568000	440000	2330000
469091	578182	236250	567576	408667	2259765	2020	524000	578000	220000	568000	440000	2330000
469091	578182	236250	567576	408667	2259765	2021	524000	578000	220000	568000	440000	2330000
469091	578182	236250	567576	408667	2259765	2022	524000	578000	220000	568000	440000	2330000
469091	578182	236250	567576	408667	2259765	2023	524000	578000	220000	570000	442000	2334000
469091	578182	236250	569557	408667	2261746	2024	524000	578000	220000	570000	441000	2333000
469091	578182	236250	569557	408667	2261747	2025	524000	578000	220000	570000	441000	2333000
469091	578182	236250	569557	408667	2261747	2026	524000	578000	220000	570000	441000	2333000
469091	578182	236250	569557	408667	2261746	2027	524000	578000	220000	570000	441000	2333000
469091	578182	236250	569557	408667	2261746	2028	524000	578000	220000	572000	441000	2335000
469091	578182	236250	572336	408667	2264526	2029	524000	578000	220000	572000	441000	2335000
469091	578182	236250	572336	408667	2264526	2030	524000	578000	220000	572000	441000	2335000
469091	578182	236250	572336	408667	2264526	2031	524000	578000	220000	572000	441000	2335000
469091	578182	236250	572336	408667	2264526	2032	524000	578000	230000	572000	441000	2345000
469091	578182	236250	572336	408667	2264526	2033	524000	578000	230000	572000	442000	2346000
469091	578182	236250	572336	408667	2264526	2034	524000	578000	230000	572000	442000	2346000
469091	578182	236250	572336	408667	2264526	2035	524000	578000	230000	572000	442000	2346000
469091	578182	236250	572336	408667	2264526	2036	524000	578000	233000	572000	442000	2349000
469091	578182	236250	572336	408667	2264526	2037	524000	578000	233000	572000	442000	2349000
469091	578182	236250	572336	408667	2264526	2038	524000	578000	233000	572000	442000	2349000
469091	578182	236250	572336	408667	2264526	2039	524000	578000	233000	572000	442000	2349000
469091	578182	236250	572336	408667	2264526	2040	524000	578000	233000	572000	442000	2349000
469091	578182	236250	572336	408667	2264526	2041	524000	578000	233000	572000	443000	2350000
469091	578182	236250	572336	408667	2264526	2042	524000	578000	245000	572000	443000	2362000
469091	578182	236250	572336	408667	2264526	2043	524000	578000	245000	572000	443000	2362000
469091	578182	236250	572336	408667	2264526	2044	524000	578000	245000	572000	443000	2362000
469091	578182	236250	572336	408667	2264526	2045	524000	578000	245000	572000	443000	2362000
469091	578182	236250	572336	408667	2264526	2046	524000	578000	245000	572000	444000	2363000
469091	578182	236250	572336	408667	2264526	2047	524000	578000	245000	581000	444000	2372000
469091	578182	236250	581377	408667	2273566	2048	524000	578000	245000	610000	444000	2401000
469091	578182	236250	610446	408667	2302635	2049	524000	578000	245000	641000	444000	2432000
469091	578182	236250	640968	408667	2333158	2050	524000	578000	245000	673000	444000	2464000
469091	578182	236250	673016	408667	2365206	2051	524000	578000	245000	707000	445000	2499000
469091	578182	236250	706667	408667	2398857	2052	524000	578000	245000	718000	445000	2510000

Appendix 4.1. MES Model: Base Case (IRR, NPV and Total Cost per ha)

A. IRR (%)

			Plantation Size (ha)												
Management Regime	Species	Code	5000	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000	150000	200000
Watershed Part Protection Commercial	*Albizzia falcataria*	M1S1	5.7	7.1	7.9	8.2	8.4	8.5	8.6	8.6	8.6	8.7	8.7	8.8	8.8
WPPC	*Calliandra calothyrsus*	M1S2	5.6	7.0	7.8	8.1	8.2	8.3	8.4	8.5	8.5	8.5	8.5	8.6	8.7
	Dalbergia latifolia	M1S3	6.3	7.3	7.9	8.1	8.2	8.3	8.3	8.4	8.4	8.4	8.4	8.5	8.5
Hutan Tanaman Industri-Transmigrasi	*Albizzia falcataria*	M2S1	6.4	7.5	8.2	8.4	8.5	8.6	8.6	8.7	8.7	8.7	8.7	8.8	8.8
HTIT	*Eucalyptus deglupta*	M2S2	6.4	7.5	8.2	8.4	8.5	8.6	8.7	8.7	8.7	8.7	8.8	8.8	8.8
	Gmelia arborea	M2S3	6.4	7.4	7.9	8.2	8.3	8.3	8.4	8.4	8.4	8.5	8.5	8.5	8.5
Industrial Grade Timber	*Eucalyptus deglupta*	M3S1	6.4	7.4	8.1	8.3	8.5	8.5	8.6	8.6	8.6	8.7	8.7	8.7	8.8
IGT	*Eucalyptus urophylla*	M3S2	7.6	8.8	9.5	9.8	9.9	10.0	10.0	10.1	10.1	10.1	10.2	10.2	10.2
	Gmelia arborea	M3S3	7.2	8.2	8.8	9.0	9.1	9.2	9.2	9.3	9.3	9.3	9.3	9.4	9.4
Pulp Plantation	*Acacia mangium*	M4S1	5.5	6.8	7.6	7.9	8.0	8.1	8.2	8.2	8.3	8.3	8.3	8.4	8.4
PP	*Eucalyptus deglupta*	M4S2	6.1	7.1	7.7	8.0	8.1	8.2	8.2	8.3	8.3	8.3	8.3	8.4	8.4
	Eucalyptus urophylla	M4S3	6.1	7.1	7.8	8.0	8.1	8.2	8.2	8.3	8.3	8.3	8.3	8.4	8.4

B. NPV per ha @ 8% Discount Rate ($/ha)

	Plantation Size (ha)												
Code	5000	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000	150000	200000
M1S1	(277)	(98)	(9)	20	35	44	50	54	58	60	62	68	71
M1S2	(288)	(110)	(21)	9	24	33	38	43	46	48	50	56	59
M1S3	(282)	(103)	(13)	17	32	40	46	51	54	56	58	64	67
M2S1	(242)	(68)	19	49	63	72	78	82	85	87	89	95	98
M2S2	(241)	(67)	20	49	64	72	78	82	86	88	90	96	99
M2S3	(277)	(98)	(8)	22	37	45	51	56	59	61	63	69	72
M3S1	(250)	(76)	11	40	55	64	70	74	77	79	81	87	90
M3S2	(58)	116	204	233	247	256	262	266	269	271	273	279	282
M3S3	(147)	33	122	152	167	176	182	186	189	192	194	200	203
M4S1	(309)	(131)	(42)	(12)	3	11	17	22	25	27	29	35	38
M4S2	(294)	(119)	(32)	(3)	11	20	26	30	33	36	38	43	46
M4S3	(292)	(118)	(31)	(1)	13	22	28	32	35	37	39	45	48

C. Total Cost per ha ($/ha)

	Plantation Size (ha)												
Code	5000	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000	150000	200000
M1S1	3,795	3,575	3,464	3,428	3,409	3,398	3,391	3,386	3,382	3,379	3,376	3,369	3,365
M1S2	3,771	3,551	3,440	3,403	3,385	3,374	3,367	3,361	3,357	3,354	3,352	3,345	3,341
M1S3	4,496	4,270	4,157	4,119	4,100	4,089	4,081	4,076	4,072	4,069	4,066	4,059	4,055
M2S1	4,082	3,879	3,777	3,743	3,726	3,716	3,709	3,704	3,700	3,698	3,695	3,689	3,685
M2S2	4,051	3,847	3,746	3,712	3,695	3,685	3,678	3,673	3,669	3,666	3,664	3,657	3,654
M2S3	4,506	4,280	4,167	4,130	4,111	4,099	4,092	4,087	4,083	4,079	4,077	4,069	4,066
M3S1	4,056	3,853	3,751	3,717	3,700	3,690	3,683	3,678	3,674	3,672	3,669	3,663	3,659
M3S2	4,053	3,850	3,748	3,714	3,697	3,687	3,680	3,675	3,672	3,669	3,667	3,660	3,656
M3S3	4,517	4,291	4,178	4,140	4,121	4,110	4,103	4,097	4,093	4,090	4,087	4,080	4,076
M4S1	3,789	3,569	3,458	3,422	3,403	3,392	3,385	3,380	3,376	3,373	3,370	3,363	3,359
M4S2	4,046	3,842	3,740	3,706	3,689	3,679	3,672	3,668	3,664	3,661	3,659	3,652	3,649
M4S3	4,048	3,844	3,743	3,709	3,692	3,681	3,675	3,670	3,666	3,663	3,661	3,654	3,651

Appendix 4.2. MES Model: 3% Increase in Costs as Sensitivity 1 (IRR, NPV and Total Cost per ha)

A. IRR (%)

Management Regime	Species	Code	Plantation Size (ha) 5000	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000	150000	200000
Watershed Part Protection Commercial	*Albizzia falcataria*	M1S1	5.4	6.7	7.5	7.8	8.0	8.1	8.2	8.2	8.2	8.3	8.3	8.4	8.4
WPPC	*Calliandra calothyrsus*	M1S2	5.4	6.7	7.4	7.7	7.9	8.0	8.0	8.1	8.1	8.1	8.2	8.2	8.3
	Dalbergia latifolia	M1S3	6.1	7.1	7.6	7.8	8.0	8.0	8.1	8.1	8.1	8.1	8.2	8.2	8.2
Hutan Tanaman Industri-Transmigrasi	*Albizzia falcataria*	M2S1	6.2	7.2	7.9	8.1	8.2	8.3	8.3	8.4	8.4	8.4	8.4	8.5	8.5
HTIT	*Eucalyptus deglupta*	M2S2	6.2	7.2	7.9	8.1	8.2	8.3	8.3	8.4	8.4	8.4	8.4	8.5	8.5
	Gmelia arborea	M2S3	6.1	7.1	7.7	7.9	8.0	8.1	8.1	8.1	8.2	8.2	8.2	8.2	8.3
Industrial Grade Timber	*Eucalyptus deglupta*	M3S1	6.1	7.2	7.8	8.0	8.2	8.2	8.3	8.3	8.3	8.4	8.4	8.4	8.4
IGT	*Eucalyptus urophylla*	M3S2	7.4	8.5	9.2	9.5	9.6	9.7	9.7	9.8	9.8	9.8	9.8	9.9	9.9
	Gmelia arborea	M3S3	7.0	8.0	8.5	8.8	8.9	8.9	9.0	9.0	9.0	9.1	9.1	9.1	9.1
Pulp Plantation	*Acacia mangium*	M4S1	5.2	6.5	7.2	7.5	7.7	7.7	7.8	7.9	7.9	7.9	7.9	8.0	8.0
PP	*Eucalyptus deglupta*	M4S2	5.8	6.8	7.5	7.7	7.8	7.9	7.9	7.9	8.0	8.0	8.0	8.1	8.1
	Eucalyptus urophylla	M4S3	5.8	6.9	7.5	7.7	7.8	7.9	7.9	8.0	8.0	8.0	8.0	8.1	8.1

B. NPV per ha @ 8% Discount Rate ($/ha)

Code	Plantation Size (ha) 5000	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000	150000	200000
M1S1	(312)	(134)	(45)	(15)	(0)	9	15	19	22	25	27	33	36
M1S2	(323)	(145)	(56)	(26)	(12)	(3)	3	8	11	13	15	21	24
M1S3	(320)	(141)	(51)	(21)	(6)	3	9	13	16	19	21	27	30
M2S1	(279)	(105)	(17)	12	26	35	41	45	48	50	52	58	61
M2S2	(278)	(104)	(16)	13	27	36	42	46	49	51	53	59	62
M2S3	(333)	(136)	(46)	(16)	(1)	8	14	18	21	24	26	32	35
M3S1	(287)	(112)	(25)	4	18	27	33	37	40	43	45	50	53
M3S2	(95)	80	167	196	211	219	225	229	232	235	237	243	245
M3S3	(185)	(5)	84	114	129	138	144	148	151	154	156	162	165
M4S1	(345)	(166)	(77)	(48)	(33)	(24)	(18)	(14)	(11)	(8)	(6)	(0)	3
M4S2	(330)	(156)	(69)	(40)	(25)	(16)	(11)	(6)	(3)	(1)	1	7	10
M4S3	(329)	(154)	(67)	(38)	(23)	(15)	(9)	(5)	(2)	1	3	9	11

C. Total Cost per ha ($/ha)

Code	Plantation Size (ha) 5000	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000	150000	200000
M1S1	3,879	3,658	3,548	3,511	3,493	3,482	3,475	3,469	3,465	3,462	3,460	3,453	3,449
M1S2	3,854	3,634	3,523	3,487	3,468	3,457	3,450	3,445	3,441	3,438	3,435	3,428	3,424
M1S3	4,597	4,371	4,258	4,220	4,201	4,190	4,183	4,177	4,173	4,170	4,167	4,160	4,156
M2S1	4,174	3,971	3,869	3,835	3,818	3,808	3,801	3,796	3,792	3,790	3,787	3,780	3,777
M2S2	4,142	3,939	3,837	3,803	3,786	3,776	3,769	3,764	3,760	3,758	3,755	3,749	3,745
M2S3	4,608	4,382	4,269	4,231	4,212	4,201	4,194	4,188	4,184	4,181	4,178	4,171	4,167
M3S1	4,148	3,944	3,842	3,808	3,791	3,781	3,774	3,769	3,766	3,763	3,761	3,754	3,750
M3S2	4,145	3,941	3,839	3,805	3,788	3,778	3,771	3,766	3,763	3,760	3,758	3,751	3,748
M3S3	4,619	4,393	4,280	4,242	4,223	4,212	4,204	4,199	4,195	4,192	4,189	4,182	4,178
M4S1	3,873	3,652	3,542	3,505	3,487	3,476	3,469	3,463	3,459	3,456	3,454	3,447	3,443
M4S2	4,137	3,933	3,831	3,797	3,780	3,770	3,764	3,759	3,755	3,752	3,750	3,743	3,740
M4S3	4,139	3,935	3,834	3,800	3,783	3,773	3,766	3,761	3,757	3,754	3,752	3,745	3,742

Appendix 4.3. MES Model: 0.3% & 0.1% Increase in Non Pulp Log & Pulp Log Prices as Sensitivity 2 (IRR, NPV and Total Cost per ha)

A. IRR (%)

Management Regime	Species	Code	Plantation Size (ha)												
			5000	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000	150000	200000
Watershed Part Protection Commercial	*Albizzia falcataria*	M1S1	6.2	7.6	8.5	8.8	9.0	9.1	9.2	9.2	9.3	9.3	9.3	9.4	9.4
WPPC	*Calliandra calothyrsus*	M1S2	6.2	7.6	8.4	8.7	8.9	9.0	9.1	9.1	9.1	9.2	9.2	9.3	9.3
	Dalbergia latifolia	M1S3	6.7	7.7	8.3	8.5	8.6	8.7	8.7	8.8	8.8	8.8	8.8	8.9	8.9
Hutan Tanaman Industri-Transmigrasi	*Albizzia falcataria*	M2S1	6.9	8.0	8.7	8.9	9.0	9.1	9.2	9.2	9.2	9.3	9.3	9.3	9.4
HTIT	*Eucalyptus deglupta*	M2S2	6.9	8.0	8.7	8.9	9.0	9.1	9.2	9.2	9.2	9.3	9.3	9.3	9.4
	Gmelia arborea	M2S3	6.8	7.7	8.3	8.5	8.6	8.7	8.8	8.8	8.8	8.8	8.9	8.9	8.9
Industrial Grade Timber	*Eucalyptus deglupta*	M3S1	6.8	7.9	8.6	8.8	8.9	9.0	9.1	9.1	9.1	9.2	9.2	9.2	9.3
IGT	*Eucalyptus urophylla*	M3S2	8.1	9.2	10.0	10.2	10.4	10.5	10.5	10.6	10.6	10.6	10.6	10.7	10.7
	Gmelia arborea	M3S3	7.5	8.5	9.1	9.4	9.5	9.6	9.6	9.6	9.7	9.7	9.7	9.8	9.8
Pulp Plantation	*Acacia mangium*	M4S1	6.0	7.4	8.2	8.5	8.7	8.8	8.8	8.9	8.9	9.0	9.0	9.0	9.1
PP	*Eucalyptus deglupta*	M4S2	6.5	7.6	8.3	8.5	8.6	8.7	8.8	8.8	8.8	8.8	8.9	8.9	8.9
	Eucalyptus urophylla	M4S3	6.5	7.6	8.3	8.5	8.6	8.7	8.8	8.8	8.8	8.9	8.9	8.9	8.9

B. NPV per ha @ 8% Discount Rate ($/ha)

Code	Plantation Size (ha)												
	5000	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000	150000	200000
M1S1	(218)	(40)	49	79	94	103	108	113	116	118	120	126	129
M1S2	(227)	(49)	41	70	85	94	100	104	107	110	112	118	121
M1S3	(229)	(49)	40	70	85	94	100	104	107	110	112	118	121
M2S1	(175)	(1)	86	115	130	139	145	149	152	154	156	162	165
M2S2	(175)	(1)	86	115	130	139	144	148	152	154	156	162	165
M2S3	(222)	(43)	47	77	91	100	106	111	114	116	118	124	127
M3S1	(188)	(14)	73	103	117	126	132	136	139	141	143	149	152
M3S2	13	187	274	303	318	326	332	336	340	342	344	350	353
M3S3	(90)	89	179	208	223	232	238	243	246	248	250	256	259
M4S1	(247)	(69)	20	50	65	74	80	84	87	90	92	98	101
M4S2	(229)	(55)	32	61	76	84	90	94	98	100	102	108	111
M4S3	(228)	(54)	34	63	77	86	92	96	99	101	103	109	112

C. Total Cost per ha ($/ha)

Code	Plantation Size (ha)												
	5000	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000	150000	200000
M1S1	3,795	3,575	3,464	3,428	3,409	3,398	3,391	3,386	3,382	3,379	3,376	3,369	3,365
M1S2	3,771	3,551	3,440	3,403	3,385	3,374	3,367	3,361	3,357	3,354	3,352	3,345	3,341
M1S3	4,496	4,270	4,157	4,119	4,100	4,089	4,081	4,076	4,072	4,069	4,066	4,059	4,055
M2S1	4,082	3,879	3,777	3,743	3,726	3,716	3,709	3,704	3,700	3,698	3,695	3,689	3,685
M2S2	4,051	3,847	3,746	3,712	3,695	3,685	3,678	3,673	3,669	3,666	3,664	3,657	3,654
M2S3	4,506	4,280	4,167	4,130	4,111	4,099	4,092	4,087	4,083	4,079	4,077	4,069	4,066
M3S1	4,056	3,853	3,751	3,717	3,700	3,690	3,683	3,678	3,674	3,672	3,669	3,663	3,659
M3S2	4,053	3,850	3,748	3,714	3,697	3,687	3,680	3,675	3,672	3,669	3,667	3,660	3,656
M3S3	4,517	4,291	4,178	4,140	4,121	4,110	4,103	4,097	4,093	4,090	4,087	4,080	4,076
M4S1	3,789	3,569	3,458	3,422	3,403	3,392	3,385	3,380	3,376	3,373	3,370	3,363	3,359
M4S2	4 046	3,842	3,740	3,706	3,689	3,679	3,672	3,668	3,664	3,661	3,659	3,652	3,649
M4S3	4,048	3,844	3,743	3,709	3,692	3,681	3,675	3,670	3,666	3,663	3,661	3,654	3,651

Appendix 4.4 MES Model: Combination of 3% Increase in Costs, 0.3% Increase in Non Pulp Log Price & 0.1% Pulp Log Price as Sensitivity 3 (IRR, NPV and Total Cost per ha)

A. IRR (%)

			Plantation Size (ha)												
Management Regime	Species	Code	5000	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000	150000	200000
Watershed Part Protection Commercial	*Albizzia falcataria*	M1S1	5.9	7.3	8.1	8.4	8.6	8.7	8.8	8.8	8.9	8.9	8.9	9.0	9.0
WPPC	*Calliandra calothyrsus*	M1S2	5.9	7.2	8.1	8.4	8.5	8.6	8.7	8.7	8.8	8.8	8.8	8.9	8.9
	Dalbergia latifolia	M1S3	6.5	7.4	8.0	8.2	8.3	8.4	8.5	8.5	8.5	8.5	8.5	8.6	8.6
Hutan Tanaman Industri-Transmigrasi	*Albizzia falcataria*	M2S1	6.7	7.7	8.4	8.6	8.7	8.8	8.9	8.9	8.9	8.9	9.0	9.0	9.0
HTIT	*Eucalyptus deglupta*	M2S2	6.7	7.7	8.4	8.6	8.7	8.8	8.9	8.9	8.9	9.0	9.0	9.0	9.1
	Gmelia arborea	M2S3	6.6	7.5	8.1	8.3	8.4	8.4	8.5	8.5	8.5	8.6	8.6	8.6	8.6
Industrial Grade Timber	*Eucalyptus deglupta*	M3S1	6.6	7.6	8.3	8.5	8.6	8.7	8.8	8.8	8.8	8.9	8.9	8.9	8.9
IGT	*Eucalyptus urophylla*	M3S2	7.9	9.0	9.7	10.0	10.1	10.2	10.2	10.3	10.3	10.3	10.3	10.4	10.4
	Gmelia arborea	M3S3	7.3	8.3	8.9	9.1	9.2	9.3	9.3	9.4	9.4	9.4	9.4	9.5	9.5
Pulp Plantation	*Acacia mangium*	M4S1	6.3	7.3	8.0	8.2	8.3	8.4	8.4	8.5	8.5	8.5	8.5	8.6	8.6
PP	*Eucalyptus deglupta*	M4S2	6.3	7.3	8.0	8.2	8.3	8.4	8.4	8.5	8.5	8.5	8.5	8.6	8.6
	Eucalyptus urophylla	M4S3	6.3	7.3	8.0	8.2	8.3	8.4	8.5	8.5	8.5	8.5	8.6	8.6	8.6

B. NPV per ha @ 8% Discount Rate ($/ha)

	Plantation Size (ha)												
Code	5000	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000	150000	200000
M1S1	(254)	(75)	14	43	58	67	73	77	80	83	85	91	94
M1S2	(262)	(84)	5	35	50	59	65	69	72	75	77	83	86
M1S3	(266)	(87)	2	32	47	56	62	66	70	72	74	80	83
M2S1	(212)	(38)	50	79	93	102	108	112	115	117	119	125	128
M2S2	(212)	(38)	50	79	93	102	108	112	115	118	119	125	128
M2S3	(260)	(81)	9	39	54	63	69	73	76	79	81	87	90
M3S1	(225)	(50)	37	66	80	89	95	99	102	105	107	112	115
M3S2	(24)	150	238	267	281	290	296	300	303	305	307	313	316
M3S3	(128)	51	141	171	185	194	200	205	208	210	212	218	221
M4S1	(282)	(104)	(15)	15	30	38	44	49	52	54	56	62	65
M4S2	(266)	(91)	(4)	25	39	48	54	58	61	64	65	71	74
M4S3	(264)	(90)	(3)	26	41	50	55	59	63	65	67	73	76

C. Total Cost per ha ($/ha)

	Plantation Size (ha)												
Code	5000	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000	150000	200000
M1S1	3,879	3,658	3,548	3,511	3,493	3,482	3,475	3,469	3,465	3,462	3,460	3,453	3,449
M1S2	3,854	3,634	3,523	3,487	3,468	3,457	3,450	3,445	3,441	3,438	3,435	3,428	3,424
M1S3	4,597	4,371	4,258	4,220	4,201	4,190	4,183	4,177	4,173	4,170	4,167	4,160	4,156
M2S1	4,174	3,971	3,869	3,835	3,818	3,808	3,801	3,796	3,792	3,790	3,787	3,780	3,777
M2S2	4,142	3,939	3,837	3,803	3,786	3,776	3,769	3,764	3,760	3,758	3,755	3,749	3,745
M2S3	4,608	4,382	4,269	4,231	4,212	4,201	4,194	4,188	4,184	4,181	4,178	4,171	4,167
M3S1	4,148	3,944	3,842	3,808	3,791	3,781	3,774	3,769	3,766	3,763	3,761	3,754	3,750
M3S2	4,145	3,941	3,839	3,805	3,788	3,778	3,771	3,766	3,763	3,760	3,758	3,751	3,748
M3S3	4,619	4,393	4,280	4,242	4,223	4,212	4,204	4,199	4,195	4,192	4,189	4,182	4,178
M4S1	3,873	3,652	3,542	3,505	3,487	3,476	3,469	3,463	3,459	3,456	3,454	3,447	3,443
M4S2	4,137	3,933	3,831	3,797	3,780	3,770	3,764	3,759	3,755	3,752	3,750	3,743	3,740
M4S3	4,139	3,935	3,834	3,800	3,783	3,773	3,766	3,761	3,757	3,754	3,752	3,745	3,742

Appendix 5.2. **Diskette Forms ***

Diskette No.	File Name	Description
①	**Minimum Economic Size (MES) Application**	
		• developed in Quattro Pro for *Windows*
	format.wb1	• format application (including macros)
	10.wb1	• output file
	species.wb1	• species data
	ranges.wb1	• weighted and updated data format
	library.wb1	• control file (including macros)
②	**Forestland Allocation Model**	
		• developed in spreadsheet application (with MES & U/L limits)
	x_1ul, x_2ul,...x_6ul.wk1	• objectives 1, 2,......,6 files
	xvul.wk1	• MINMAX formulation file
	xvwul.wk1	• MINSUM formulation file
	$xvul_1$, $xvul_2$,...$xvul_6$.wk1	• MINMAX formulation file different weights
	$xvwul_1$, $xvwul_2$,...$xvwul_6$.wk1	• MINSUM formulation file different weights
	Optimisation & Simulation	
		• set up in FOLPI and RMS-2020
	case4.prb or com	• problem files (optimisation)
	case4.sum	• summary file (optimisation)
	10.des & 15.des	• description files
	10.run & 15.run	• command files
	sum10a10	• summary file (simulation)
	y10a10	• yield file (simulation)

Note: * sample files